Personal Electronic Math Tutor

Final Design Report

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Sincerely,

Jeremy Ashinghurst
Scott Eshleman
Phil Gilde

ABSTRACT

The Burkina Math Tutor Team designed and built a personal electronic math tutor. The finished product was a hand-held unit that is intended to help young students living in Mahadaga, Burkina Faso gain a conceptual understanding of numbers and basic arithmetic.

1. INTRODUCTION

1.1 Description

The ability to understand and comprehend basic mathematical concepts is an important skill. In their visits to Burkina Faso and discussions with teachers in local towns, the Education Group of the Collaboratory, under the direction of Dr. Angela Hare, discovered that many students have difficulty conceptualizing mathematical concepts. While they can recite factual arithmetic problems, they struggle when trying to apply these problems to real situations. In an effort to provide a solution to this problem, our team designed the Personal Electronic Math Tutor to teach conception arithmetic through word problems and pictures.

1.2 Objectives

1. To create and test all necessary circuitry and a PCB layout of a personal electronic math tutor geared toward children of ages 6 to 12 who live in Mahadaga, Burkina Faso. The math tutor will stress conceptual, rather than factual, understanding.
2. To program a microprocessor with a simple program designed by the Collaboratory's Education Group. The math problems contained in the program will be easily reprogrammable by teachers in Burkina Faso and will be limited to addition, subtraction, division, and multiplication of numbers no greater than 20.
3. To find and order a 128x128 monochrome graphic indicator for the math tutor that will be large enough to display the desired program and be easily readable in direct sunlight.
4. To create a capability for the use of an external power source for battery charging purposes.
5. To design a math tutor that has a material cost of less than $80 per unit for thirty units. This target cost includes batteries for one year and does not include tooling and assembly labor cost.

6. To design a product housing that is impact resistant and dust impenetrable. If there is enough time and financial resources, create the housing and assemble a final working prototype.

1.3 Literature Review

Due to the educational nature of this project, it became necessary to do some background research into educational tools currently on the market. There are many companies that provide elementary math education software, but of particular interest to this group was firstly, whether or not that software taught basic math operations in conjunction with skills such as visual quantity recognition, and secondly, if such software was available on hand-held electronics.

In the research conducted, very few companies actually produced the kind of educational programs that we were seeking to put onto our electronic math tutor. AAA Math provides CD's that contain addition and subtraction problems where the student must look at two groups of blocks, for example, identify the number of blocks in each group, and perform the requested mathematical operation.[1] However, they do not have similar problems that allow for practice with multiplication and division. Candybyte.com is another source that provides similar programs to AAA Math (addition and subtraction)[2]. Sheila Stevens also offers visual mathematical problems, which are available for free download on their site[3], but unfortunately these problems are all the same format, resulting in lack of variety and reduction of the operation to a drill rather than a game. In general, however, the kind of software we plan to implement on the electronic math tutor is not currently available on the market.

Not only was there a lack of this type of educational material available, but all of the software that resembled ours was only available for the computer.

[1] AAAMath. "AAAMath Main page." 29 November 2007. http://aaamath.com
[2] Candybyte Software. "Candybyte Main Page" 05 Feb. 2004, 29 Nov. 2007. http://candybyte.com/
[3] Basic Skills Resources. "Simple Arithmetic." 29 Nov. 2007. basicskills.sheilastevens.info/arith10.htm

Because we are trying to implement this kind of software on a hand-held electronic device, this was rather encouraging, seeing as we could be potentially breaking some ground here. In our research, however, we did discover a few companies producing hand-held educational videogaming. Both Leapfrog[4] and Vtech[5] produce such a platform and use it to operate elementary educational software, such as spelling, basic math, and reading. Leapfrog produces the Leapster Learning Game System[6], which is an interactive videogaming system with programs that are quite similar to our proposed programs. It is equipped with a full color LCD screen and a variety of educational programs teaching skills ranging from phonics and spelling to mathematics. Vtech also offers a similar learning device called the VSmile.[7] Its programs are games that require the user to learn mathematic and English skills in order to progress. Like the Leapster, it also has a full color LCD screen and a comfortable button layout. Both of these systems are quite impressive and in many ways could be considered superior to our proposed system. However, one thing these devices do not have is built-in solar cells for recharging purposes. These devices do operate off batteries, but the companies both recommend the use of alkaline batteries. These systems are also in English, whereas our system will display French text.

Even though these particular educational tools did not operate off of solar power, it was very important to this project to determine what kind of hand-held electronic devices with graphical displays were powered with solar energy. The types of devices most similar to the math tutor are calculators and personal digital assistants (PDAs). After researching companies such as Canon[8], Casio[9], TI[10], and Sharp[11] it appears fairly consistent across the board that calculators

[4] Leapfrog. "Leapfrog Main Page." 4 Dec. 2007. http://leapfrog.com/en/shop.html
[5] VTech. "VTech Main Page." 4 Dec. 2007. http://vtech.com/
[6] Leapfrog. "Leapster Learning Game System – Pink Edition." 4 Dec. 2007. http://leapfrog.com/en/families/leapster/leapster_learning0/leapsterpink.html
[7] VTech. "VTech Press Release." 4 Dec. 2007. http://www.vtech.com/press/files/vsmile_pocket_eng_final.pdf
[8] Canon. "Calculators." 29 Nov. 2007. http://www.usa.canon.com/consumer/controller?act=ProductCatIndexAct&fcategoryid=110
[9] Casio. "Calculators and Dictionaries." 29 Nov. 2007. http://www.casio.com/products/
[10] TI, education technology. "Products." 29 Nov. 2007. http://education.ti.com/educationportal/sites/US/productHome/us_product.html

with graphical screens do not operate on solar power or have solar charging built into them. Some companies do carry scientific calculators with the option of solar operation, but these screens are alpha-numeric instead of graphical. We were also unable to find any PDAs that operated off of solar power. Silicon Solar Inc. does make solar battery chargers for PDAs but solar power does not come standard on PDAs.[12]

According to Solar Energy International, photovoltaic systems have the advantage of reliability in harsh conditions, durability, low maintenance cost, no fuel cost, and safety.[13] All these factors are extremely important in our implementation. Disadvantages include higher initial cost, variability of solar radiation, and the necessity of an energy storage method.[14] Although these disadvantages are significant, we should be able to achieve adequate solutions. Solar Energy International notes two possible implementation systems. The first is a day use system, in which stand-alone appliances are wired directly to a DC appliance, a technique commonly used in calculators and small toys,[15] while the second is a direct current system with storage batteries.[16] We will probably be using the latter type of system, since the children will be using the tutors inside dimly lit classrooms. This type of system requires a controller to prevent batteries from discharging too deeply or overcharging.[16]

In *Solar Electricity*, Simon Roberts gives two types of rechargeable batteries used in solar systems: lead-acid and nickel-cadmium.[17] We will most likely be using nickel-cadmium batteries for their low voltage applicability and safety. A rechargeable battery undergoes two charging cycles. It goes through a shallow cycle each day, and a deep cycle over days or weeks of cloudy weather in which the total power use for the day does not equal the total charging

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[11] Sharp USA. "Products and Support." 29 Nov. 2007. http://www.sharpusa.com/global/SiteMap/
[12] Silicon Solar. "Main Page." 4 Dec. 2007. http://www.siliconsolar.com/
[13] Solar Energy International. Photovoltaics: Design and Installation Manual. (Gabriola Island: New Society Publishers, 2004.) 3.
[14] Solar Energy International 3.
[15] Solar Energy International 4.
[16] Solar Energy International 5.
[17] Roberts, Simon. Solar Electricity: A Practical Guide to Designing and Installing Small Photovoltaic Systems. (Cambridge: Prentice Hall, 1991.) 37.

power.[18] All batteries undergo self-discharging over time, which is amplified by heat.[19] Characteristics of good solar system batteries include high cycle life for deep cycles, low maintenance, high charging efficiency, the ability to survive complete discharge, low rate of self-discharge, reliability, and minimum change in performance over operating temperature range.[20] We must be careful to take all of these characteristics into account when choosing our battery.

Even after we know how to go about producing a photovoltaic system, the amount of sunlight we can gather is critical to know, as it will regulate how fast the batteries charge. According to the website of Apricus, a solar water heater manufacturer, the average levels of insolation in Africa are approximately 6.02 $kWh/m^2/day$, or approximately 500 W/m^2 over a 12-hour daylght period.[21]

An example of a solar product powered by a solar cell is a simple solar yard light. In "How Solar Yard Lights Work," Marshall Brain describes how these types of lights work.[22] The light uses a battery, LED, and controller board. The battery is a common NiCd AA battery that produces approximately 1.23 volts, while the solar array uses four cells which collectively produce about 1.8V. A diode is wired in series with the solar array and battery to prevent reverse current from flowing into the solar cell. The LED draws 45mA and can produce light for about 15 hours with a fully charged battery. Hopefully, our entire circuit will use less than 45mA, so our charging time verses operating time objective will be easy to realize.

Since low power consumption is critical in our application, we have to choose our two power-consuming components, the LCD and the microcontroller, very carefully. Therefore, it becomes necessary to find the state of the art for both microcontrollers and LCDs in terms of power requirements and to weigh these options with the requirements of our project.

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[18] Simon 45.
[19] Simon 44.
[20] Simon 45.
[21] Whitlock, C. E., et al., Release 3: NASA Surface Meteorology and Solar Energy Data Set for Renewable Energy Industry Use. Rise & Shine 2000, the 26th Annual Conference of the Solar Energy Society of Canada Inc. and Solar, Oct. 21-24, 2000, Halifax, Nova Scotia, Canada.
[22] Brain, Marshall. "How Solar Yard Lights Work" HowStuffWorks.com. 30 Sept. 2007. http://home.howstuffworks.com/solar-light.htm

For our microcontroller, the TI MSP430 series of microcontrollers were chosen primarily due to their incredibly low power requirements – even the most advanced chip, the MSP430FG4619, consumes only 400uA in full operating mode, and can consume as little as .35uA in its most power-conserving standby mode.[23] The MSP430 also supports very large amounts of memory (up to 120KB), which may be required for the project.

The amount of power we draw may be largely dependent upon the LCD display, especially given the fact that the LCD may not be put into a 'low power standby' mode briefly like the microcontroller can. When the microcontroller is waiting for user input and not executing any code, it can be put into a standby mode to conserve power. The LCD cannot be put into a standby mode, since the time the microcontroller is waiting for user input is the time when the user will be looking at the problem on the LCD screen and thinking about the answer. Thus whenever the device must wait for user input, it is imperative that the LCD be on. Not only is the LCD the component most likely to consume excessive power, but it is the one component that has been specified the most, that is, there are many more constraints on what the LCD needs to do than on any other component. The LCD must be able to display crude images as well as text, and it must do so legibly. Not only must it be able to display text and images, but the screen must be large enough to display the entirety of the given word problem, including graphical representations. This limits our choices of LCD's greatly. Generally the smaller an LCD, the cheaper it is and the less power it consumes. Also, the lower the resolution, the fewer controller chips must be employed, which lowers cost. So a small LCD with a low resolution will consume less power and money than a large, higher-resolution LCD. After careful consideration of the project requirements, we determined that a 128x128 graphical LCD with at least a 3-inch diagonal would be desirable.

Pacific Display device's 128x128 LCD has a typical current consumption maximum of 10mA, without the backlight, which then goes up to 230mA when an

[23] Texas Instruments. "MSP430xG461x Mixed Signal Microcontroller." 30 November, 2007. http://focus.ti.com/lit/ds/symlink/msp430fg4619.pdf

LED backlight is turned on.[24] A similar but not exactly the same (192x128) display by Topway Display draws a maximum on 43mA by itself, and 153mA with backlight.[25] Thus the display we choose may be dependent upon our expected lighting conditions: a device for use in low light should run better with a backlight, while a device for use in sun would be better off with a lower unlit current consumption. The LCD we eventually decided on has a current draw of only 14.1mA in character mode, with the backlight drawing 180mA.[26] Since we do not plan on using the backlight at all, the LCD will always consume less than our solar panels can put out (100mA).

1.4 Solution

Given the problem this group was asked to solve, many different plans could have been implemented. One possible solution could have been writing programs for use on the computer systems already present in Burkina Faso. This would have been a much simpler course of action because it would have used technology that was already available, thus making the cost lower as well. The problem with this solution would have centered on use of a shared resource, as not every student could use a computer during class time. While this could have been done, it seemed to detract from the overall goal of allowing the teachers to work with the students using an interactive tool. The condition and availability of the computers was also unknown.

Teaching packets could also have been created and given to the teachers to aid them in their instruction of the students. This, however, did not seem very helpful as the teachers already knew the problems their students were having and what to do to help solve them.

Another possible solution would have been to purchase an appropriate product currently on the market and deliver these to the teachers in Burkina

[24] Pacfic Display. "LCD Component Data Sheet." 26 September, 2007. http://www.pacificdisplay.com/gdm/GDM-128128-00.pdf
[25] Shenzen Topway Display. "LCD Module User Manual." 26 September, 2007. http://www.topwaydisplay.com/Pub/Manual/LM1095E-Manual-Rev0.1.pdf
[26] Varitronix International, Limited. "Specification of LCD module." 03 August, 2004, 29 October, 2007. http://www.varitronix.us.com/?pid=25

Faso. The advantages here would have been a high quality product, a technologically advanced device (color LCD, etc), and a rapid delivery time. However, this solution seemed more like a quick-fix approach rather than one that took in all the various factors involved in this situation. This solution also had several problem, cost being the main issue, but also that these devices may not have been designed with the West-African climate in mind.

In the end our solution seemed like the best one for a number of reasons. First of all, it provides every student with the ability to work on the problems simultaneously. It is also relatively small and easy to store. It eases the teachers' work load, as it allows the students to work on real problems while the teachers can attend to tasks such as grading or lesson planning. It also reduces the amount of paper that would be necessary for students to do this type of work. It is also more cost-effective and more appropriate for the situation than other similar products on the market. Though this device most likely costs more than many of the other alternatives, it is more appropriate given the objectives of the endeavor.

2. DESIGN PROCESS

2.1 Overall Design

The design of the PEMT and prototype program underwent several iterations. Because we originally intended the PEMT to be chargeable by solar power, the final prototype significantly differed from our first design. In the first step of the design process, we discussed what a PEMT might look like, and what parts it should include for user interface. As a result, we developed a block diagram for the unit. After some discussions within the group and with Dr. Hare, we decided we would need a large LCD screen which the user would control with a 12-key keypad. The device would be primarily run off of solar power, so a solar panel with rechargeable batteries was necessary. We also decided to include a charging option for AC power. A microprocessor would be needed to run the entire device. With this knowledge, we created a block diagram of our ideal device. The block diagram for the final prototype (solar capabilities removed) can be seen in *Figure 1*.

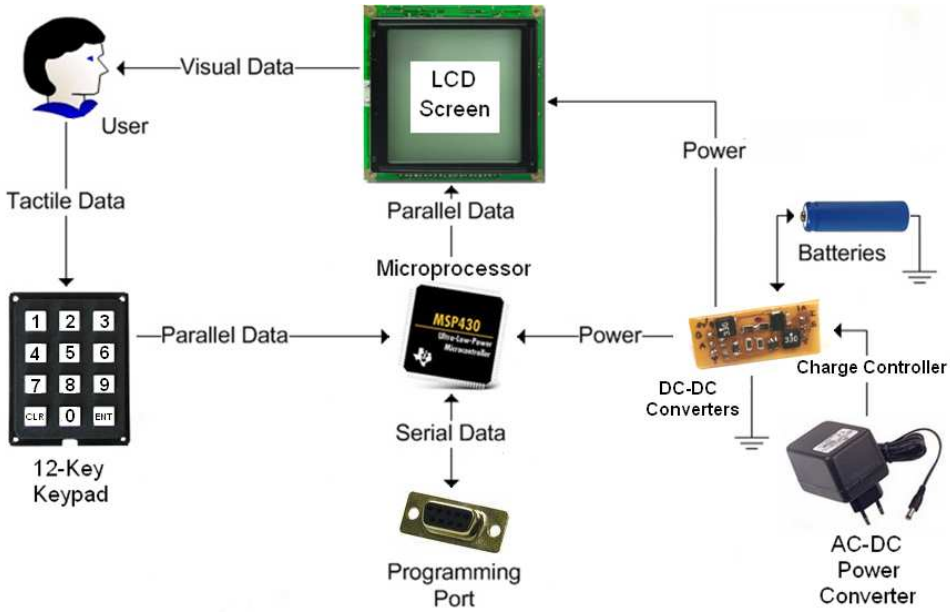

Figure 1 – Block Diagram of Final Prototype

2.2 Hardware Design

The next step was selection of the major parts, with a large focus on reducing cost while maintaining proper functionality. The 128x128 graphic LCD screen we chose was the Varitronix VL-FS-MGLS128128-31C. This screen was chosen mainly for its large 2.75 in^2 viewing area, which makes it easily readable for small children. We chose the All Electronics KP-28, as it was the least expensive 12-key keypad that we could find. We decided to use a Texas Instruments MSP430 microprocessor because of its very low current requirement.

We next designed the power configuration for the device. Our selected LCD screen required a power supply line of 5V, and a logic drive voltage line of -15V. The MSP430 required a power supply line of 3.3V. To generate these voltages, we first had to choose the type of rechargeable batteries we would use. Since we were able to find a microprocessor that consumes less than 1mA of current, and an LCD module that consumes less than 14mA of current, the team determined that two series-wired AA batteries would be adequate. This would produce a nominal voltage of 2.4V, which would be capable of generating the necessary power lines with boost circuitry while having adequate current capacity to run the device for a long time. After researching rechargeable battery chemistries, NiCd batteries were chosen because they were found to be the most rugged battery available. This is important for a harsh environment and sporadic charging and discharging. After researching the possibilities, the NCD1000AA NiCd batteries, which feature a 1000mAh capacity, were found and ordered form Zbattery.com.

The next step was choosing appropriate boost regulators to produce 5V and -15V lines. Several switching power supplies were considered, but the final choice was Maxim's MAX8569A for the 5V line. This chip only takes 7µA of supply current and produces a 5V output capable of providing up to 50mA. The 3.3V line was created through linear regulation off of the 5V line. This was achieved with Microchip's MCP1700-3302, as can be seen in *Figure 2*. For the -15V line to bias the LCD, Linear Technology's LT1617 was chosen. This

inverting DC-DC converter requires a 20µA quiescent current and can drive currents up to approximately 10mA when converting from 2.4V to -15V. A potentiometer was implemented in conjunction with this chip to create a variable voltage output. This allows for contrast adjustment of the LCD screen. This circuitry can be seen in *Figure 3*.

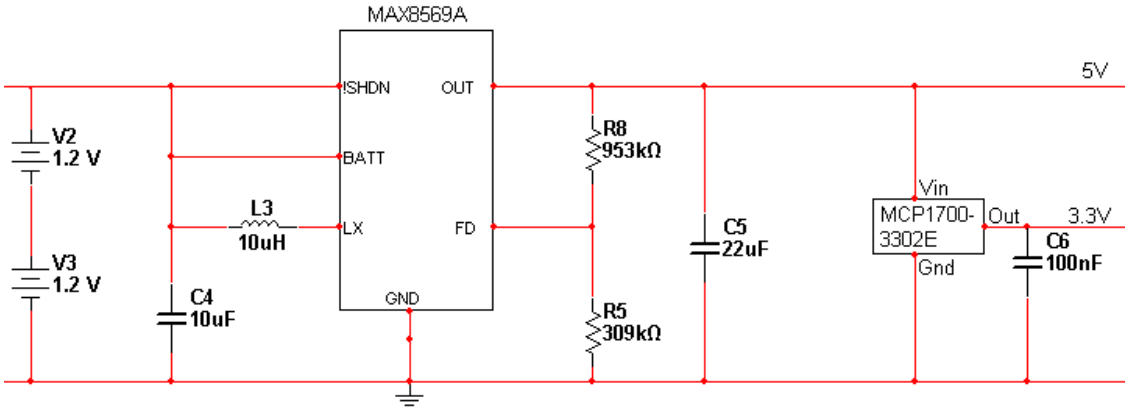

Figure 2 – 5V and 3.3V Regulation

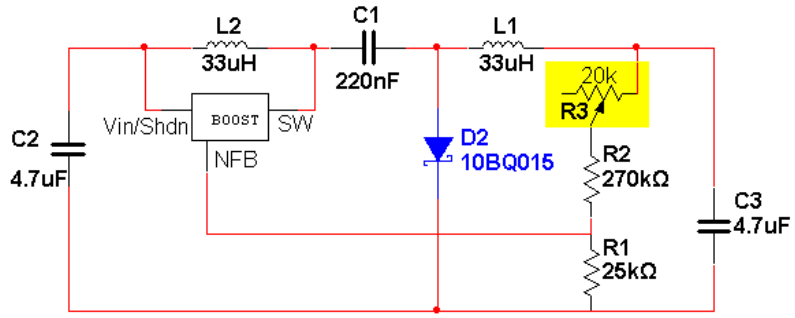

Figure 3 – -15V Regulation

After solar power technology was researched, we found that small individual solar cells did not provide a cost-effective solution or enough current to charge the batteries. Larger solar panels were researched, and after many alternatives were analyzed, a suitable panel was chosen. This was a 4V, 100mA output encapsulated panel measuring 2.36 in^2. This was connected to the two batteries with a diode in series. The diode prevented current from flowing back into the panel when the batteries are charged and the solar power source is

removed. The largest change to our design occured in February after the Collaboratory's Education Group returned from a trip to Mahadaga. Matt Walsh, a full-time engineer and missionary in Mahadaga, reported that Mahadaga has gained greater access to electricity in the past year through the implementation of additional solar arrays. The Mahadaga Handicap Center now has a charging station with 220V outlets in separate shelves. Since a solar panel adds cost to the devices, Matt Walsh and the trip team decided that the solar panel is no longer necessary. As a result, our final design allows for battery charging solely through an AC-DC power supply.

The alternating current (AC) to direct current (DC) power supply was also designed with a transformer that stepped the input down from 220Vrms to 12Vrms. The AC waveform was changed to DC through full-wave rectification. A 3.9V Zener diode and a large capacitor were placed across the output in order to provide a 3.9V output with an acceptable amount of ripple. The output was designed to provide 100mA of current. This design was not implemented in the final device. After taking the high cost of a 220Vrms transformer into consideration, along with the complexity of creating a durable housing and connector, it was found that simply purchasing a standard AC-DC power supply would be more cost effective. We found the T41-9-500D-3 power supply that outputs 500mA at 9V. It was later determined that we may need to find a power supply with more current capability.

A simple charge controller needed to be implemented in order to prevent damage to the batteries from overcharging. Due to the charging characteristics of the NiCd batteries, the battery voltage begins to decrease after full charge has been reached. Because of this, peak detection circuitry can be used to sense when this occurs and turn off the solar charging. This was originally designed with analog components, but after a discussion with Black & Decker engineer Danny Brotto, this analog circuitry was abandoned for a digital solution. Since our chosen microprocessor has an unused A to D pin, by connecting the battery output directly to this pin and recording the voltage level every 30 seconds, we can sense when the peak voltage level occurs. A resistor divider network was

used to ensure the input battery voltage was in a suitable voltage range for the MSP430. Another microprocessor output pin was utilized to connect and disconnect the solar panels from the batteries when necessary. An MC7805 was used to regulate the output of the AC to DC power supply to 5V. The two 1Ω resistors limit the charging current to 500mA. The charging circuitry can be seen in *Figure 4*.

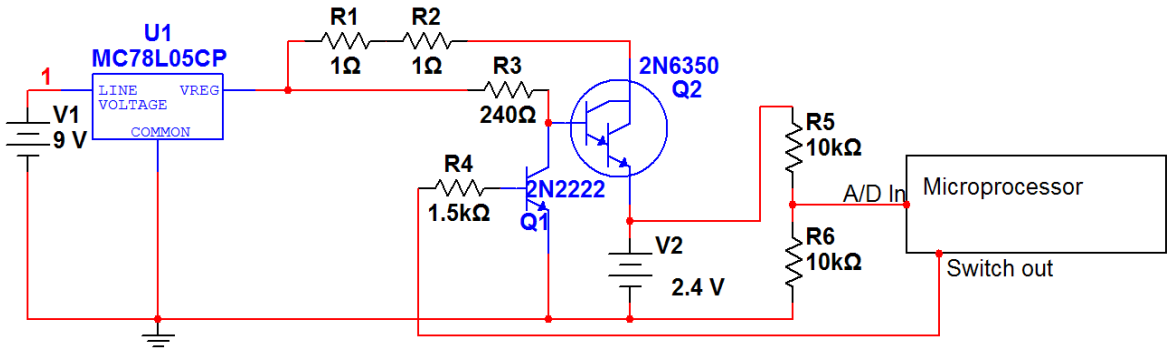

Figure 4 – Charging Circuitry

The design of the turn-on and turn-off sequence also became challenging. The 3.3V must always remain on to allow the microprocessor to control the battery charging circuitry. The 5V line to the LCD must always be turned on before the -15V line, and it was found after discussions with Ralph Sabroff, a Varitronix applications engineer, the 5V line must be turned off after or at the exact same time as the -15V line. In order to accomplish this, we connected a double pole, single throw (DPST) switch to both the 5V line leading to the LCD and the -15V line leading to the LCD. We also allowed one MSP430 input pin to sense when this 5V line was active, and connected an output pin to a chip enable on the -15V regulator. When the switch is thrown on, both the 5V lines and the -15V lines to the LCD are active, but only the 5V line is supplying power. The MSP430 senses this high voltage, and turns on the -15V chip enable after a short delay. When the switch is thrown off, both the 5V line and the -15V line are turned off immediately. The MSP430 the senses the low voltage on the 5V line and turns off the -15V chip enable to prepare for the next power on sequence. This design can be seen in *Figure 5*.

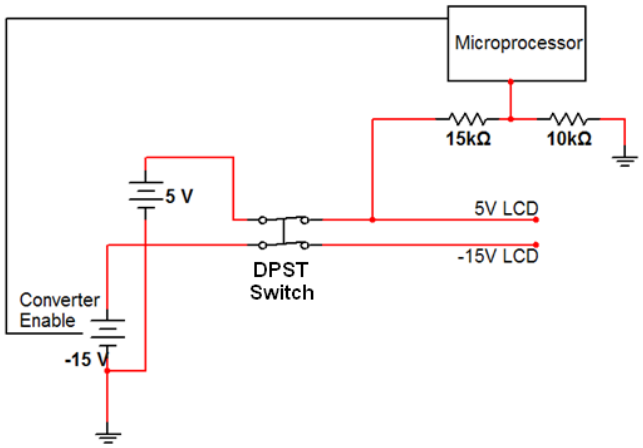

Figure 5 – On/Off circuitry

2.3 Software Design

The first step in developing software was to select the MSP430 microprocessor that would meet our needs. Originally, we chose to design the program with the MSP430FG1617, because this chip had one of the greatest functionality. We knew that this was a much greater microprocessor than what was needed, but we decided that we did not want to risk running out of port pins or programmable flash memory early on. After completing the prototype program, we decided that the MSP430F2274, a lower cost microprocessor, would be more suitable for the application. One event that influence this decision was the donation of an emulator device, an eZ430-RF, by Texas Instruments during a MSP430 seminar that our team attended in March. This emulator, specially designed to program our chosen microprocessor, has a USB interface to a computer and a 9-pin connector interface with the PEMT.

The design of the PEMT sample program was challenging. The goal was to help students conceptualize mathematics rather than to simply drill them with problems. We attempted to accomplish this by using word problems. We designed a menu screen that would allow the user to choose from addition, subtraction, division, or multiplication. We decided to give the user ten problems of the selected type before redisplaying the menu screen. For each word problem, the problem would be written at the top of the screen in French. The

middle of the screen would then display the problem graphically in a way that visually reinforces the arithmetic concept. For addition, we designed people to display on the LCD. We asked how many total people would be at the market, if there were a certain number of people already at the market, and another quantity of people joined them. For subtraction, we asked how many ladybugs would remain if a certain number flew away. We displayed the ladybugs on the screen and represented the ones that had flown away with large X's. For division, we asked the user how many fish would be in each basket if we divided them equally between a certain number of baskets. On the screen, fish were displayed directly above the baskets to show how many fish would be in each. For multiplication, we asked the total number of ladybugs if there were a set number of sticks and a certain number of ladybugs on each stick. Once again, ladybugs were displayed directly above the sticks on the LCD screen so the user could easily see the total number of ladybugs for each situation. The user would receive feedback from the LCD after inputting an answer, telling if the problem was answered correctly. We decided to allow the user to input three incorrect answers before providing the correct answer and moving to the next problem. A statistics screen would be displayed that showed the number of problems answered correctly and the number of tries.

The program was written in C-code using IAR's Embedded Workbench. The overall program flow chart can be seen in *Figure 6*. This program was designed with four C files. The ProblemSelectorMainAlt.c file is the main file that runs the high level program operation. This file initializes the LCD, as well as contains the interrupt for the on/off power switching method described above. The ProblemSelectorAlt.c file handles the detailed program operation. It is responsible for randomly generating the numbers for each problem. This is currently performed by performing an algorithm on the input to the A to D converter. This file calls the LCDControl.c file in order to display the problem screens. It also calls the Input.c file to get user input, and it handles this user input, checking the accuracy of the user's answers. It is also responsible for displaying the menu screen, calculating statistics, and displaying the statistics

screen. The LCDControl.c file is responsible for initializing the LCD, creating graphics, and displaying the addition, subtraction, division, and multiplication screens. It also handles any commands written to the LCD, and performs status checks to ensure that the LCD screen is ready to handle data and commands. The Input.c file captures any input from the user through the keypad, and transforms this input into the correct integer. The complete contents of each C-file can be viewed in Appendix E.

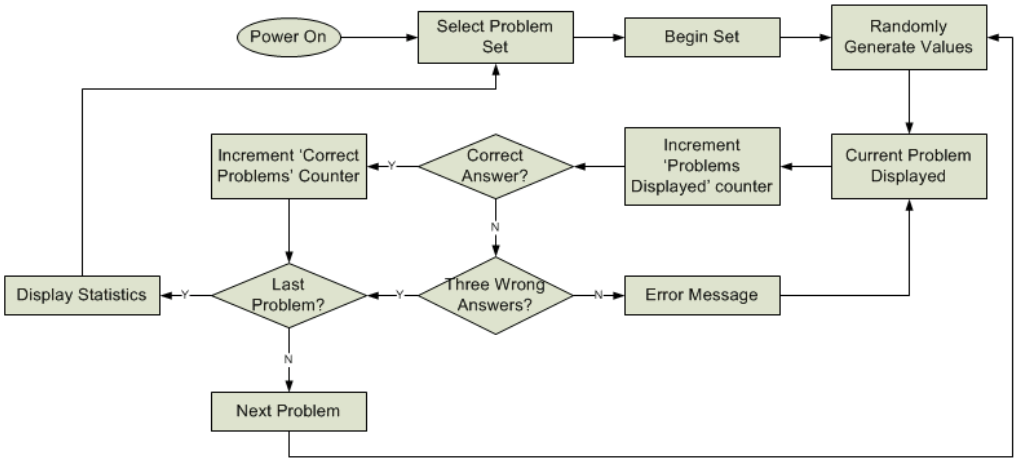

Figure 6 – PEMT Prototype Program Flow Chart

3. IMPLEMENTATION

3.1 Construction

The construction of the device was a long process. First of all, we had to create a breadboard prototype to test out each individual component of the design. See Figure 7 for a photograph of the testbed platform we used. This allowed us to hook debugging LED's to the MCU if necessary, or swap out components, switch around wires to change port configurations, etc. From there, printed circuit boards (PCB's) were designed to hold the main board, individual power boards, CPU, etc. In all, four PCB's were designed: one to hold the CPU on its own separate board for easy swapping if required, one for the 5 and 3.3V generators so that if they died they could be replaced, one for the -15V board as it was having problems during its formation, and we thought it best for it to be modular. The final board was the mainboard, which served as sort of the motherboard of the entire system. Only the battery charging and power switching circuitry were on this board; everything else was headers for other components. See Figure 8 for a view of the entire unit.

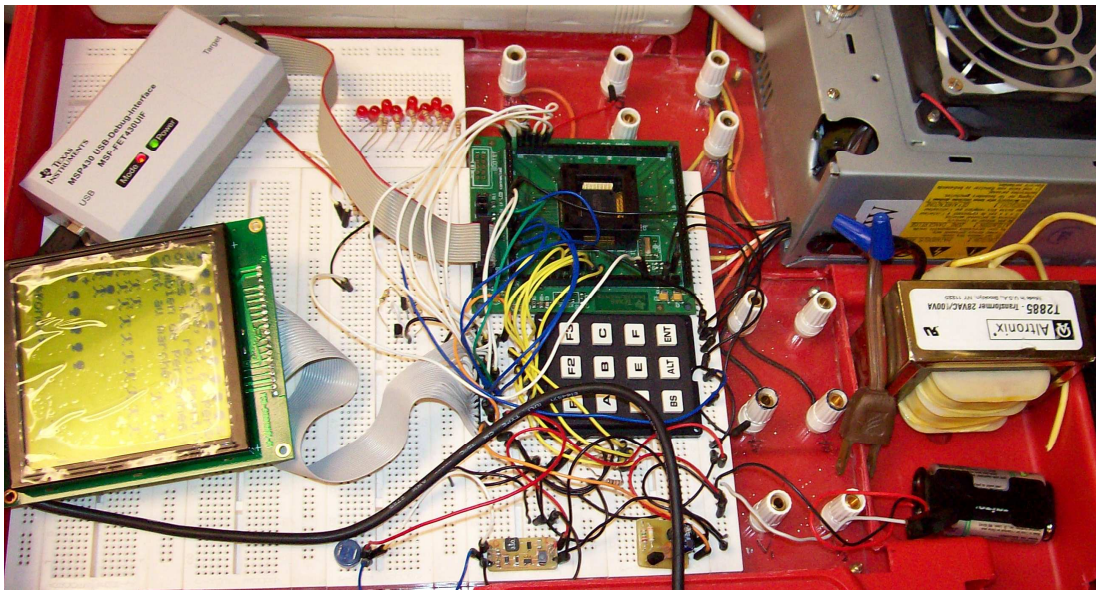

Figure 7 – PEMT Breadboard Prototype

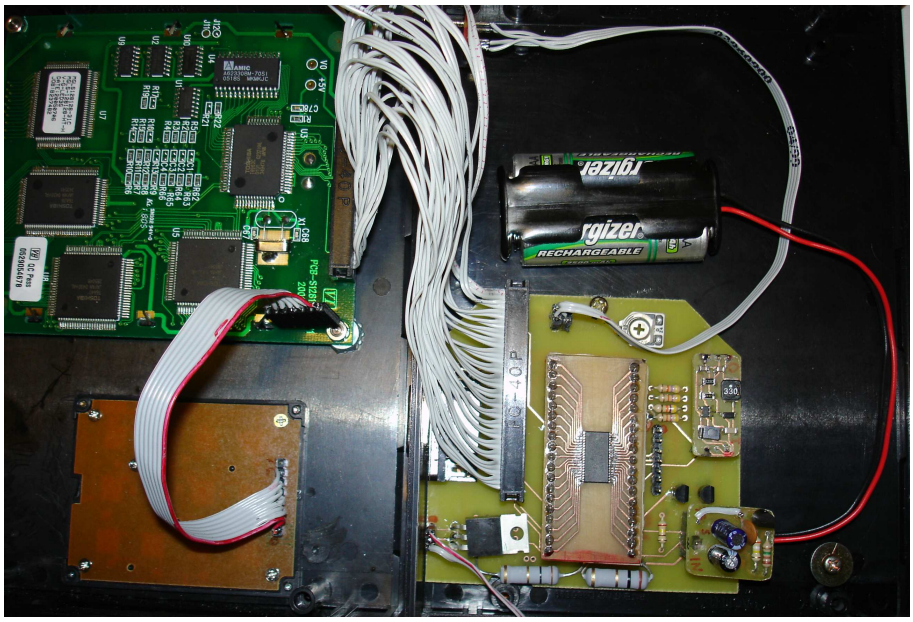

Figure 8– PEMT PCB Prototype

Once we had completed basic design of the circuits we would need in our unit and bought all our parts, we were told that we would not, in fact, have to power the device photovoltaically.

Unfortunately, the question of how to program the device became a big problem, and it seemed the easiest answer was to use TI's own (relatively inexpensive) ez-430USB stick. The protocols supported by the ez-430, however, necessitated a change in microcontroller. The ez-430 could only program an MSP430 by a 2-wire method, whereas our original debug device supported TI's full JTAG interface, which is 14 pins. Because of this, we needed to switch to one of TI's physically smaller packages, specifically lower pin count. Of TI's entire microcontroller lineup, there were only two microcontrollers that we felt met our requirements: the MSP430F2274 and the MSP430F2254. These two processors both have an identical number of pins, 38, and the same amount of flash memory, 32 KB. We felt anything less than this would probably not fit all the code we would write.

Another interesting design change during implementation was the addition of a power switch. Though there will never be a power disconnect from the microprocessor, we did decide to implement a hardware/software power switch

that would interrupt power to the LCD's power lines, and would then turn on or off the enable line form the -15V supply. This is required because the LCD cannot have the -15V line on while the 5V line is not on or established. So turning on the 5V and -15V on at the same time would not be good, since the 5V line would not necessarily be stable before the -15V. Thus the microcontroller turns on the enable pin once it detects that the 5V is stable, ensuring safe powerup of the LCD.

Due to the change in processor, new PCB's had to be designed and code had to be changed to fit the new microcontroller. Fortunately, since the 'final design' was on a PCB, not on a breadboard, there were few wires going everywhere and enclosing the project became a simple matter of cutting appropriate-sized holes in a sampled enclosure to fit the parts in the right spots. This enclosure would not stand up to the environment it would see under actual operation.

3.2 Operation

The device operated within expected parameters.

We were not able to get the chance to do extensive testing on our finished product, considering the fact that we were not able to even get the final design working without the assistance of the debugger.

On powerup, the device will briefly display a welcome screen. It will then display a selection menu from which the user can select addition, subtraction, division, and multiplication problems. In each problem set, the user is presented with a series of 10 problems, which the user must enter the answer for. If the user gets the problem wrong, it ill let them know and tell them to try again. The exception to this rule is if the same problem has been repeated three times. Then it will move on to a separate problem. Once 10 problems have been displayed and answered (or not answered, as the case may be, the device will display a statistics screen that informs the user of their performance, giving the number of times a problem was presented to them and the number of times they answer correctly. They may then touch any button to continue back to the main

menu, where they may select another problem set. The output LCD screens can be viewed in Appendix D.

The operation of the power on/power off switch was tested on the original microprocessor and does in fact work. The microcontroller is able to detect the power switch and turn on or off the -15V line appropriately. The battery charging system was implemented in hardware on both the breadboard and PCB prototypes. However, we never got the chance to test out how it functioned on the microcontroller. The only system we were able to verify was that the battery charging circuit did in fact supply the batteries with enough power to charge and that, once the microcontroller detected the peak, would effectively shut off power to the batteries, preventing them from being over-charged.

We were able to run some tests on our charge controller and 5V boost converter, both helping us conclude that we would indeed be able to meet our run-time specification. As you can see in figures 9 and 10, the battery would be able to run for 4 hours on a 1-hour charge. This was figured out because we calculated that the total current draw for the device would be 25 mA. But since all main power must run through the 5V and 3.3V generator and the converter has approximately 50% calculated efficiency at 2.4V and 16mA, our total current consumption would be approximately 50mA. We then set our charging circuit up to charge for an hour, then discharge at 50mA. When we ran this test, we discovered that it would run for four hours before the battery charge was at the level it had been at prior to charging.

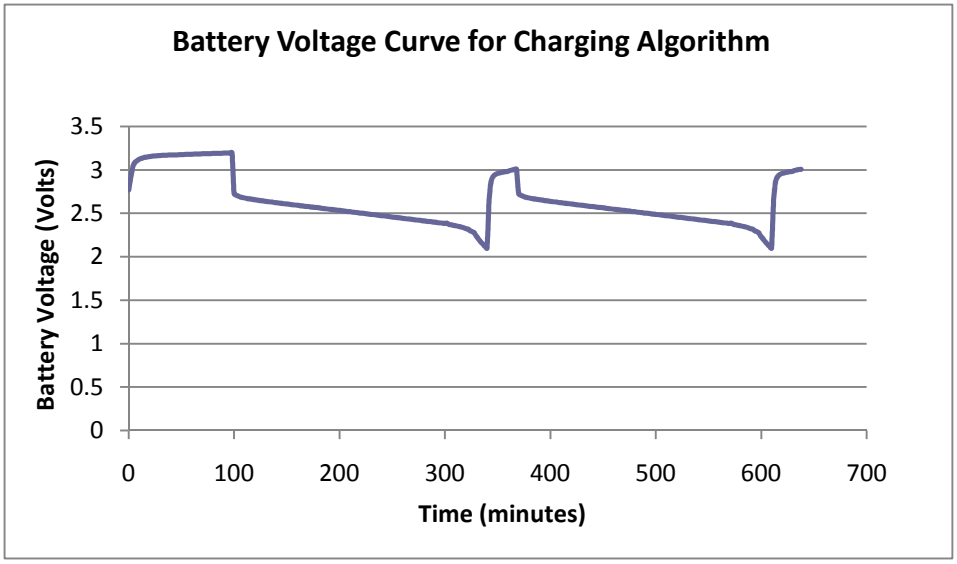

Figure 9– Battery run time at 50mA

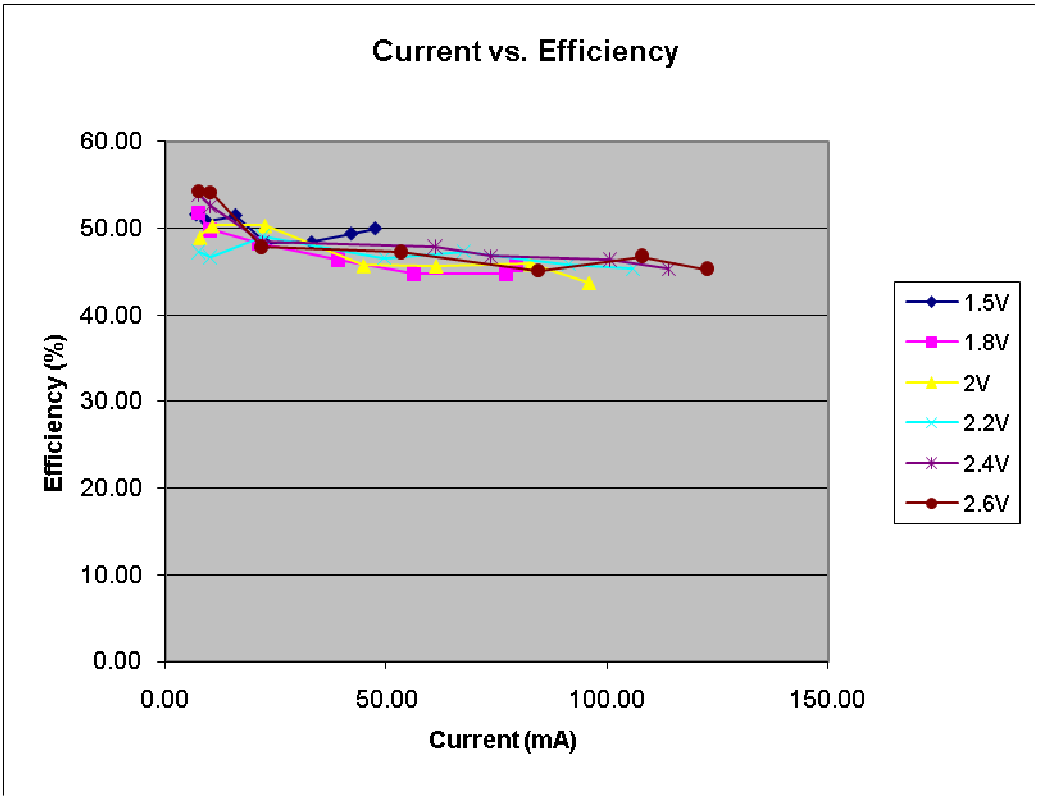

Figure 10– MAX8569 testing

4. PROJECT MANAGEMENT

4.1 Project Organization

Project work was delegated on a weekly basis to the three project team members, Jeremy Ashinghurst, Scott Eshleman, and Phil Gilde. The work was divided in equal proportions to all team members and was directed toward team member's knowledge and abilities. All team members assisted with design reports and presentations.

Jeremy Ashinghurst was our team manager and was responsible for keeping our project binder up to date and managing project deadlines. He played a crucial role in selecting an LCD screen. He created the final PCB layout, built the board, and assembled the final prototype unit. He worked in all aspects of hardware development.

Scott Eshleman researched solar panels and battery options for the PEMT. He was responsible for developing and testing the power supply circuitry. He designed the final LCD screens and wrote all the code that controls the LCD output.

Phil Gilde was responsible for finding a suitable microprocessor and selecting a keypad for the device. He wrote all code that handles user input through the keypad and wrote code for the overall operation of the device. He was also primarily responsible for developing the charging circuitry.

The project was divided into two semesters. In the fall semester, the team focused on defining the capabilities of the device, finding suitable components and creating the necessary circuitry. In the spring semester, the team focused on developing the software for the prototype program. We also focused on building and testing the final PEMT prototype.

4.2 Scheduling

For the most part, the original Gantt chart was followed well during the fall semester. We were able to find and order an LCD screen, solar panel, and keypad slightly earlier than we anticipated. Unfortunately, there were unforeseen difficulties in our keypad order, but we were able to obtain the keypads before December. Our plans for the microprocessor changed slightly. A working microprocessor was secured, but the final decision on the actual microprocessor was made in the spring after writing the prototype program. By the milestone listed, we had a good idea of the type of MSP430 we needed, and samples were ordered.

In the spring semester, we fell significantly behind our deadlines. This was due to the largest snag we encountered while working on this project: an inability to display characters and graphics on the LCD screen followed by an inability to control the LCD display. It took nearly two months longer than expected to be able to fully control the LCD. The main problem was the need to perform a status check after the command to turn on the display. As a result, our program was not completed until much later and some testing was condensed. The following are actual completion times of important milestones. A condensed version of the original Gantt chart can be viewed in Appendix B.

Milestones

- Project proposal completed 10/01/07
- LCD screen ordered 10/10/07
- Solar panels ordered 10/10/07
- Input keyboard ordered 10/17/07
- Microprocessor sampled 10/29/07
- Microprocessor circuit designed 11/07/07
- First Power supply designed 11/07/07
- Complete circuitry bread boarded and tested 11/26/07
- Final desired program specified 12/01/07
- EDR presented 12/07/07

- Complete program flow chart created 01/09/08
- Discuss information learned from January trip 02/07/08
- Working LCD output 03/24/08
- Final program finished 04/19/08
- Components soldered onto milled PCB 04/25/08
- Entire assembly with program tested 04/30/08
- Charging circuitry testing performed 05/01/08
- Final design presentation presented 05/02/08

5. BUDGET

There is a slight difference between our prototype costs and our production costs. Noting that our production costs were based on 30 units, it is not surprising that the difference is not greater. This is also due to the fact that most of the very expensive items did not have a price break at the higher order numbers. Therefore, our final prototype cost was $101.93 and our final production cost was $96.20. Not included in the budget breakdown were the gifts in kind. This included an emulator from Texas Instruments with a part number of EZ430-RF2500. See Appendix C for Budget.

6. CONCLUSIONS

We did not meet all of our objectives, though we did accomplish the most important ones. We had six main objectives; we accomplished numbers 1, 2, and 3 which dealt primarily with the basic functionality of the device as a learning tool. To this end we have met our objectives. Some of the finer objectives, however, such as weather resistance and unit cost, however, were unable to be reached this time. Another of our initial objectives, to have photovoltaic charging, was deemed unnecessary mid-project.

In light of our objectives, the project was a functional success, with some work left to be done by subsequent teams.

We have learned a great deal about integrating hardware together while writing software for it simultaneously. Since we ended with a different microcontroller than we started out with, we have had to rewrite some of our program code for different ports, while the program code itself was already under development. Another lesson we've learned is to always know everything about all of your components. Most of our spring semester time was spent trying to figure out how to get the LCD to display data; if we would had a thorough datasheet, our problems would have been fewer.

7. FUTURE WORK

This project leaves a substantial amount to be done in terms of future work. The software we created is a good sample of what the device can do, but in actuality we would like it to have greater functionality. We have not incorporated the ability to field-program the device from the device itself. Currently, writing a program to the device requires a computer to be hooked up to it, with the TI programming software running.

The future team must also perfect the battery charging circuitry. While we completed working circuitry and tested this circuitry, the test code was separate from the final PEMT code. The next team will have to incorporate the charging code into the main program, placing the microprocessor in its low-power shutdown mode when it is not taking samples. We also have a software issue in which lines of code occasionally randomly fail to write in their correct spots. We believe that sometimes the address pointer resets itself to the home address, but we were unable to determine when and why this happens. Usually refreshing the screen corrects the problem.

While the project was, in fact, a success in the sense that we made a working product, the product that we made will by no means stand up to the harsh Burkinabe environment. The casing does not incorporate any sort of weather-proof seals, for one, and is not custom-formed to the holes needed for the enclosure. A custom enclosure would be ideal, since it would be able to make it as small as possible while still fitting everything.

Overall, while there is a good amount of work to be done to bring it to full functionality, it does work in its current form. Eventually, the Education Group would like to make a PEMT that could be used by blind children. This would involve creating brail labels, and incorporating sound and/or vibration into the PEMT. Since the microprocessor we used does have a few leftover port pins, this should not be exceedingly difficult to implement. The majority of the future work will lie in perfecting the prototype to put it into a producible form, followed by building the thirty desired units.

APPENDIX A – REFERENCES

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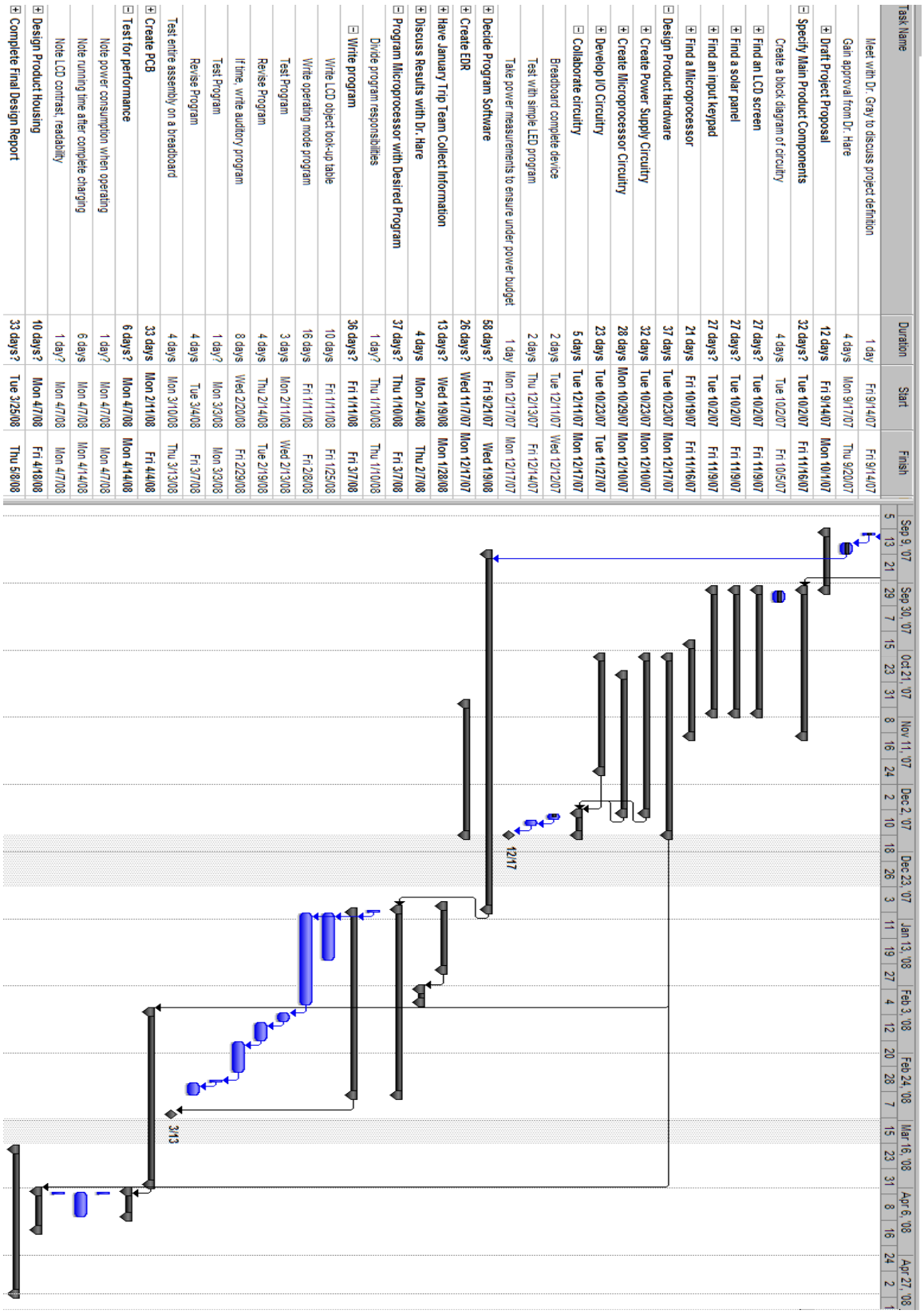
APPENDIX B – Gantt Chart

Task Name	Duration	Start	Finish
Meet with Dr. Gray to discuss project definition	1 day	Fri 9/14/07	Fri 9/14/07
Gain approval from Dr. Hare	4 days	Mon 9/17/07	Thu 9/20/07
Draft Project Proposal	12 days	Fri 9/14/07	Mon 10/1/07
Specify Main Product Components	32 days?	Tue 10/2/07	Fri 11/16/07
Create a block diagram of circuitry	4 days	Tue 10/2/07	Fri 10/5/07
Find an LCD screen	27 days?	Tue 10/2/07	Fri 11/9/07
Find a solar panel	27 days?	Tue 10/2/07	Fri 11/9/07
Find an input keypad	27 days?	Tue 10/2/07	Fri 11/9/07
Find a Microprocessor	21 days	Fri 10/19/07	Fri 11/16/07
Design Product Hardware	37 days	Tue 10/23/07	Mon 12/17/07
Create Power Supply Circuitry	32 days	Tue 10/23/07	Mon 12/10/07
Create Microprocessor Circuitry	28 days	Mon 10/29/07	Mon 12/10/07
Develop I/O Circuitry	23 days	Tue 10/23/07	Tue 11/27/07
Collaborate circuitry	5 days	Tue 12/11/07	Mon 12/17/07
Breadboard complete device	2 days	Tue 12/11/07	Wed 12/12/07
Test with simple LED program	2 days	Thu 12/13/07	Fri 12/14/07
Take power measurements to ensure under power budget	1 day	Mon 12/17/07	Mon 12/17/07
Decide Program Software	58 days?	Fri 9/21/07	Wed 1/9/08
Create EDR	26 days?	Wed 11/7/07	Mon 12/17/07
Have January Trip Team Collect Information	13 days?	Wed 1/9/08	Mon 1/28/08
Discuss Results with Dr. Hare	4 days	Mon 2/4/08	Thu 2/7/08
Program Microprocessor with Desired Program	37 days?	Thu 1/10/08	Fri 3/7/08
Divide program responsibilities	1 day?	Thu 1/10/08	Thu 1/10/08
Write program	36 days?	Fri 1/11/08	Fri 3/7/08
Write LCD object look-up table	10 days	Fri 1/11/08	Fri 1/25/08
Write operating mode program	16 days	Fri 1/11/08	Fri 2/8/08
Test Program	3 days	Mon 2/11/08	Wed 2/13/08
Revise Program	4 days	Thu 2/14/08	Tue 2/19/08
If time, write auditory program	8 days	Wed 2/20/08	Fri 2/29/08
Test Program	1 day?	Mon 3/3/08	Mon 3/3/08
Revise Program	4 days	Tue 3/4/08	Fri 3/7/08
Test entire assembly on a breadboard	4 days	Mon 3/10/08	Thu 3/13/08
Create PCB	33 days	Mon 2/11/08	Fri 4/4/08
Test for performance	6 days?	Mon 4/7/08	Mon 4/14/08
Note power consumption when operating	1 day?	Mon 4/7/08	Mon 4/7/08
Note running time after complete charging	6 days	Mon 4/7/08	Mon 4/14/08
Note LCD contrast, readability	1 day?	Mon 4/7/08	Mon 4/7/08
Design Product Housing	10 days?	Mon 4/7/08	Fri 4/18/08
Complete Final Design Report	33 days?	Tue 3/25/08	Thu 5/8/08



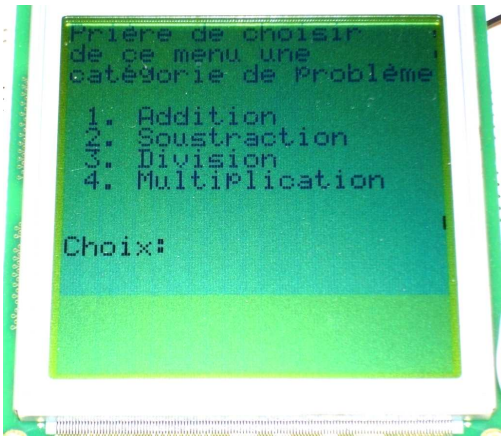
APPENDIX C – Budget

Qu.	Part Description	Digikey-Number	/Ea Price (1)	Prototype Total	/Ea. Price(30)	Production Total	Alternate Part Number
1	Power Supply	T973-P5P-ND	6.93	6.93	12.12	12.12	LH75-130
1	Housing	Pac-tec	12.12	12.12	5	5	
1	Circuit Board	N/A	5	5	3.7	3.7	
1	negative 15V Regulator	LT1617ES5#TRMPBFCT-ND	4.14	4.14	2.21	2.21	MAX8569AEUT
1	5V regulator	maxim-ic.com	2.21	2.21	0.33	0.33	
1	3V regulator	MCP1700-3302E/TO-ND	0.53	0.53	4.32	4.32	
1	Microprocessor	296-21439-1-ND	5.4	5.4	1.25	2.5	NCD1000AA
2	1000mAh NiCd batteries	Zbattery.com	1.45	2.9	3	3	KP-28
1	Numeric Keypad	All Electronics	4	4	45.00	45	VL-FS-MGLS128128-31C
1	LCD Display	Varitronix	45.00	45	0.0474	0.0474	
1	267k SMD 1206 resistor	311-267KFRCT-ND	0.088	0.088	0.047	0.047	
1	24.9k SMD 1206 resistor	RHM24.9KFCT-ND	0.047	0.047	0.229	0.458	
2	4.7uF SMD 0805 capacitor	PCC2321CT-ND	0.229	0.458	0.188	0.188	
1	SMD 1206 schottky diode	MBR0520LCT-ND	0.25	0.25	0.169	0.169	
1	SMD 1206 .22uF capacitor	PCC1887CT-ND	0.169	0.169	1.78	4.5835	
2.575	Male .1" headers (40 piece)	A34253-40-ND	1.99	5.12425	0.372	0.372	
1.75	Female .1" headers (36 Piece)	S7034-ND	1.75	3.0625	1.45	2.5375	
2	1ohm, 2W resistors	Messiah College	0.18	0.36	0.18	0.36	
3	2n222A transistors	P2N2222AGOS-ND	0.36	1.08	0.214	0.642	
1	2xAA Battery holder	BH2AA	1.37	1.37	1.234	1.234	
1	coaxial DC power connector	PJ-102A	0.38	0.38	0.33	0.33	
2	1/4W,1.5kohm resistor	Messiah College	0.06	0.12	0.06	0.12	
2	1/4W,1kohm resistor	Messiah College	0.06	0.12	0.06	0.12	
1	DPST slide switch	CKC5101-ND	2.15	2.15	1.856	1.856	
1	20kohm potentiometer	D4A,A24-ND	0.35	0.35	0.25	0.25	
2	33uH, 400mA+ inductor	495-1761-1-ND	0.64	1.28	0.58	1.16	
1	7805 vreg	LM7805CT-ND	0.47	0.47	0.372	0.372	
1	1/4W 240ohm resistor	Messiah College	0.06	0.06	0.06	0.06	
1	1/4W 1.5kohm resistor	Messiah College	0.06	0.06	0.06	0.06	
4	1/4W, 47kohm resitor	Messiah College	0.06	0.24	0.06	0.24	
1	40 pin IDC cable 6"	Newegg.com	2.49	2.49	2.49	2.49	N82E16812105909
1	22uF electrolytic capacitor	P5149-ND	0.15	0.15	0.077	0.077	
1	10uF electrolytic capacitor	P5148-ND	0.15	0.15	0.077	0.077	
1	.1uF ceramic capacitor	BC1148CT-ND	0.066	0.066	0.066	0.066	
1	1/4W, 953kOhm resistor	Messiah College	0.06	0.06	0.06	0.06	
1	1/4W, 309kOhm resistor	Messiah College	0.06	0.06	0.06	0.06	
1	10uH inductor	490-4059-1-ND	0.42	0.42	0.352	0.352	
	various wire - free				Production Total	$96.20	
	solder - free				Prototype Total	$108.86	
	DB-9 Connector - free						

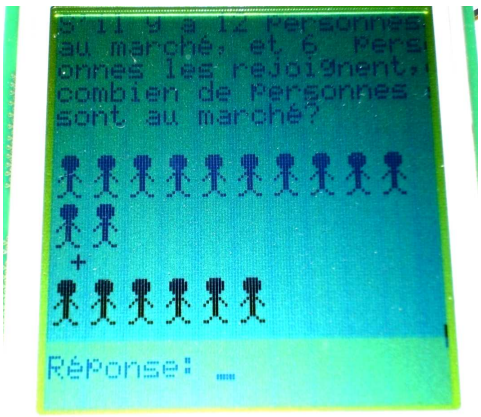
APPENDIX D – Screen Operations

Welcome

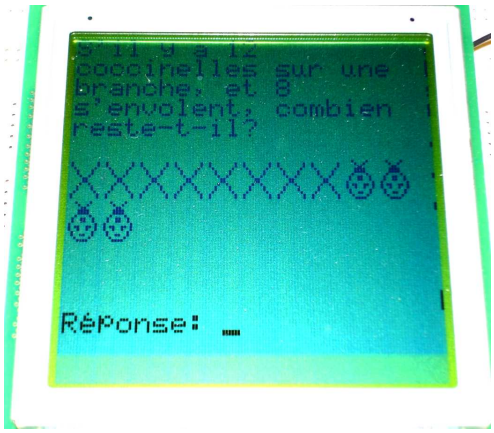
Menu



Addition



Subtraction



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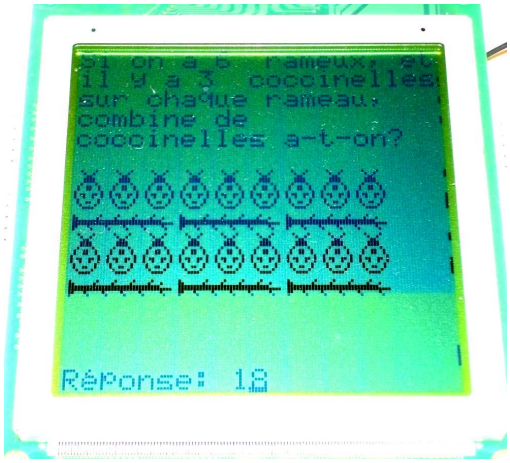
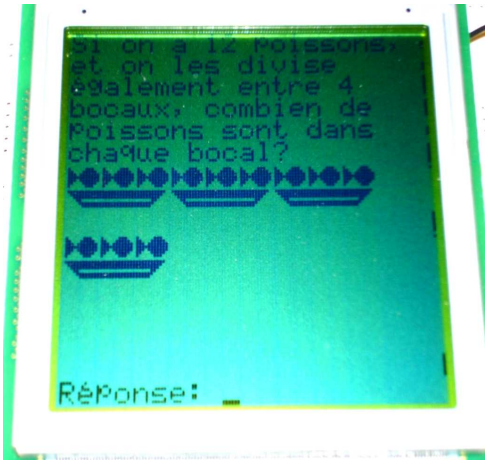
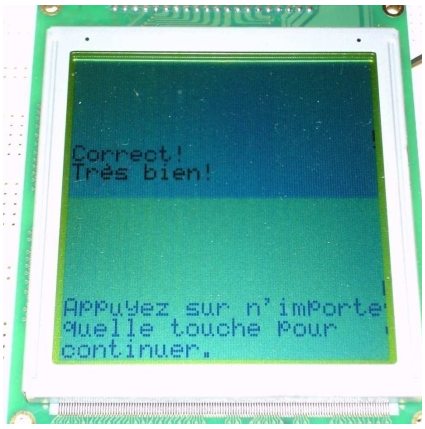


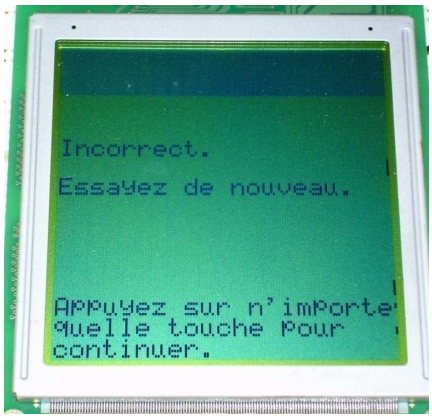
Division



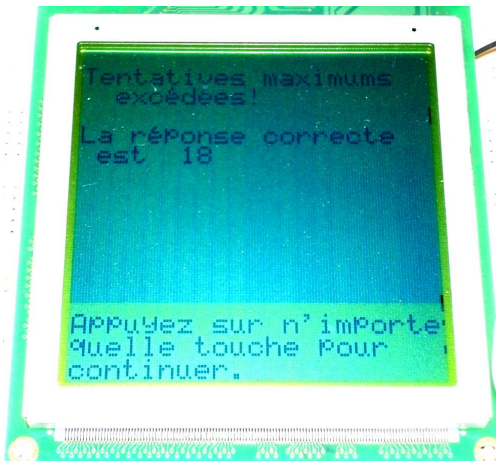
Correct Answer



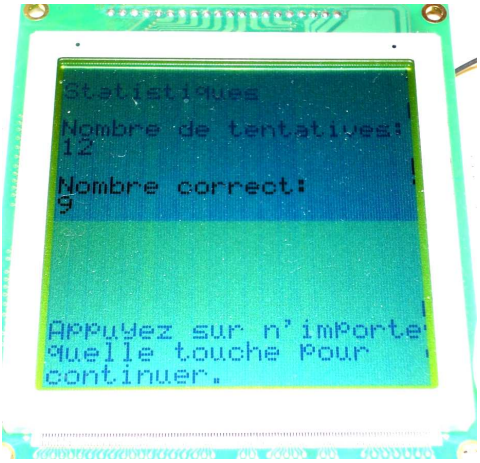
Incorrect Answer



Maximum Tries Exceeded



Statistics



APPENDIX E

ProblemSelectorMainAlt.c

```
#include "ProblemSelectorAlt.c"
#include "intrinsics.h"
#include "io430xG46x.h"

#pragma vector = PORT1_VECTOR
__raw __interrupt void powerSwitch(){

  //Pin 1.0 = 5V sense switch
  //Pin 1.2 = -15V enable

  unsigned int i =50000;                  //short delay for switch debounce
  while(i!=0){                            //and -15V supply delay (50ms min)
    i--;
  }

  __bic_SR_register(__SR_GIE);            //Disable Global Interrupt
  if((P1IN & 0x01) == 0x00){             //If Power turned off
    P1OUT &= 0xfb;                //Disable -15V
    terminate = 1;
    P1IES = 0x00;
  }
  else{                                   //Power turned on
    P1OUT |= 0x04;                //Enable -15V
    terminate = 0;
    P1IES = 0x01;
  }
  P1IFG = 0x00;                           //Clear interrupt flag
  __bis_SR_register(__SR_GIE);            //Enable Global Interrupt
}

void main(){
     int theAnswer;

     // Stop watchdog timer to prevent time out reset
     WDTCTL = WDTPW + WDTHOLD;

     terminate = 1;       //load program with power switch off
     P1DIR &= 0xfe;
     P1DIR |= 0x04;
     P1OUT &= 0xfb;              //Disable -15V
     P1IES = 0x00;        //Interrupt to occur on rising edge
     P1IE = 0x01;         //Enable interrupt on Pin 1.0
     __bis_SR_register(__SR_GIE); //Enable Global Interrupt
     while(1){
       P10OUT &= 0x00;                           // Set this pin to off
       P10DIR |= 0x01;                            // Enable shut-off pin for
batteries
       ADC12CTL0 &= 0xfffd;                      // Disable conversions
       P6SEL |= 0x01;                            // Enable A/D channel A0
       P6DIR &= 0xfe;
       ADC12CTL0 = REFON + REF2_5V + ADC12ON + SHT0_2 + MSC;
                                                  // turn on 2.5V ref, set samp
time
       ADC12CTL1 = SHP + CONSEQ_2 + CSTARTADD_0;              // Use sampling
timer and set mode
       ADC12MCTL0 = SREF_1;                      // Vr+=Vref+

       for (int i = 0x3600; i; i--);              // Delay for needed ref
start-up.
```

```
                                                  // See datasheet for details.
        ADC12CTL0 |= ENC;                        // Enable conversions
        ADC12CTL0 |= ADC12SC;                   // Start conversions
                                                  // Conversion done?
        for (double x = 0; x <1000; x++);  // Delay for next result
        if (terminate == 0){
          InitializeLCD();
          initializeVar();
          while(terminate == 0){
            displayMenu();
             while ((problemNum <=10)&&(terminate==0)){
               generateNums();                 //Generate random numbers
               theAnswer = getUserInput();     //Display problem and get answer
               checkAnswer(theAnswer);         //Check answer
               while ((count > 0)&&(terminate==0)){
                  checkAnswer(answer);
               }
             }
             displayStats();
             clearStats();
          }
        }
      }
 }
```

ProblemSelectorAlt.c

```
#include <math.h>
#include "Input.c"
#include <string.h>
#include "LCDControl.c"
#include "stdio.h"
#include "stdlib.h"

int count;       /* Variable that keeps track of number of tries on a
particular problem */
int totalTries;  /* Variable that keeps track of total tries in the problem set
*/
int problemNum;  /* Variable that keeps track of the problem number in the set
*/
int correct;     /* Variable that keeps track of correct answers per problem
set */
int firstNumber; /* First number in the addition problem */
int secondNumber;/* Second number in the addition problem */
int answer;      /* The answer for any given problem */
int option;      /* Selection for type of problem */
int result;      /* Answer user input is checked against */
int key;         /* Value corresponding to the pressed key */
int time;
int terminate;

void initializeVar(){  /* Method that initializes all global variables and
ensures random number generation */
     int voltage = ADC12MEM0;
     srand(voltage);
     count = 0;
     problemNum = 1;
     correct = 0;
     totalTries = 0;
     firstNumber = 0;
     secondNumber = 0;
     }

void displayMenu(){
```

```
    ClearScreen();

    char line1[] = "Priere de choisir";
    line1[3] = 0x8a;                        //Corresponds to accent grave
    PrintLine(line1,0);
    PrintLine("de ce menu une",1);
    char line2[] = "categorie de probleme";
    line2[3] = 0x82;                        //Corresponds to accent aigu
    line2[18] = 0x8a;
    PrintLine(line2,2);
    PrintLine(" 1. Addition",4);
    PrintLine(" 2. Soustraction",5);
    PrintLine(" 4. Multiplication",7);
    PrintLine(" 3. Division",6);
    PrintLine("Choix:  ",10);

    StatusCheck1();                         //Set cursor pointer address
    WriteData(0x07);                       //column 7
    StatusCheck1();
    WriteData(0x0a);                       //row 10
    StatusCheck1();
    WriteCommand(0x21);

    StatusCheck1();
    WriteCommand(0x97);                 //Turn cursor on
    StatusCheck1();

    option = getKey();

    StatusCheck1();
    WriteData(0xd9);                       //Set pointer address
    StatusCheck1();                        //to cursor position
    WriteData(0x00);                       //10*21+7 = 217
    StatusCheck1();
    WriteCommand(0x24);

    StatusCheck1();                         //display obtained number
    WriteData(option+0x10);
    StatusCheck1();
    WriteCommand(0xc0);

    unsigned int i = 20000;                 //delay for viewing
    do i--;
    while (i!=0);
    }

void generateNums(){
     firstNumber = (int)((floor(rand()*21.0))/32767.0); /* Generates random
number between 0-20 */
     secondNumber = (int)((floor(rand()*21.0))/32767.0); /* Generates random
number between 0-20 */
     /*Write code to display these two numbers on the screen in an addition
problem */
     }

int getUserInput(){
     int i=0;
     int j;                                   //dummy variable for decimal to
string conversion
     int input;                               //data input from user
     char numberStr1[2];                      //Number array for decimal to
string conversion
```

```
     char numberStr2[1];
     int number1,number2;
     StatusCheck1();
     WriteCommand(0x97);                 //Turn On Cursor
     StatusCheck1();
     switch (option){
            case 1: result = firstNumber + secondNumber;                 *
addition */
                   if (result > 20) {               /* Account for results
greater than 20. Regenerate numbers */
                       generateNums();
                       getUserInput();
                       }
                   else {
                     DisplayAddition(firstNumber,secondNumber,result);
                     WriteData(0x2f);         //Set pointer address to cursor
location
                     StatusCheck1();
                     WriteData(0x01);
                     StatusCheck1();
                     WriteCommand(0x24);
                     char line[] = "Reponse:    ";
                     line[1] = 0x82;          //accent aigu
                     input = getKey();       //Get user input
                     j = 20000;                    //delay before next input
                     do j--;
                     while (j!=0);
                     StatusCheck1();                          //Reset cursor
pointer address
                     WriteData(0x0a);                        //column 10
                     StatusCheck1();
                     WriteData(0x0e);                        //row 14
                     StatusCheck1();
                     WriteCommand(0x21);
                     if(input!=10){
                       j = sprintf(numberStr1,"%d",input);     //convert input
to number string
                       line[9] = numberStr1[0];
                       PrintLine(line,14);
                       number1 = atoi(numberStr1);
                       input = getKey();
                       j = 20000;                    //delay before next input
                       do j--;
                       while (j!=0);
                       i++;
                    }
                     if(input!=10){
                       j = sprintf(numberStr2,"%d",input);     //convert input
to number string
                       line[10] = numberStr2[0];
                       line[0]= 'R';                //Reset R (Disappears,
Reason Unknown)
                       PrintLine(line,14);
                       number2 = atoi(numberStr2);
                       input = getKey();
                       j = 20000;                    //delay before next input
                       do j--;
                       while (j!=0);
                       i++;
                     }
                     if(i==0){
                       answer = 0;
                     }
```

```
                    if(i==1){
                      answer = number1;
                    }
                    else{
                      answer = 10*number1 + number2;
                    }
                  }
                        break;
            case 2: result = firstNumber-secondNumber;
                    if (secondNumber > firstNumber) {                          /*
subtraction */
                       generateNums();        /* Account for negative numbers
*/
                       getUserInput();
                       }
                    else {
                    DisplaySubtraction(firstNumber,secondNumber,result);
                    WriteData(0x18);                        //Set pointer
address to cursor
                    StatusCheck1();                         //location
                    WriteData(0x01);
                    StatusCheck1();
                    WriteCommand(0x24);
                    char line[] = "Reponse:   ";
                    line[1] = 0x82;          //accent aigu
                    input = getKey();       //Get user input
                    j = 20000;                    //delay before next input
                    do j--;
                    while (j!=0);
                    StatusCheck1();                          //Reset cursor
pointer address
                    WriteData(0x0a);                        //column 10
                    StatusCheck1();
                    WriteData(0x0d);                        //row 13
                    StatusCheck1();
                    WriteCommand(0x21);
                    if(input!=10){
                      j = sprintf(numberStr1,"%d",input);     //convert input
to number string
                      line[9] = numberStr1[0];
                      PrintLine(line,13);
                      number1 = atoi(numberStr1);
                      input = getKey();
                      j = 20000;                    //delay before next input
                      do j--;
                      while (j!=0);
                      i++;
                  }
                    if(input!=10){
                      j = sprintf(numberStr2,"%d",input);     //convert input
to number string
                      line[10] = numberStr2[0];
                      line[0]= 'R';                 //Reset R (Disappears,
Reason Unknown)
                      PrintLine(line,13);
                      number2 = atoi(numberStr2);
                      input = getKey();
                      j = 20000;                    //delay before next input
                      do j--;
                      while (j!=0);
                      i++;
                    }
                    if(i==0){
```

```
                    answer = 0;
                  }
                  if(i==1){
                    answer = number1;
                    }
                  else{
                    answer = 10*number1 + number2;
                  }
                }
                      break;
          case 3: result = firstNumber/secondNumber;
                  if (secondNumber > firstNumber || secondNumber == 0 ||
firstNumber%secondNumber != 0 || result > 10){  // division
                   generateNums();                      /* Account for
results of 0 or non-integer results */
                   getUserInput();
                   }
                  else {
                  DisplayDiv(firstNumber,secondNumber,result);
                  WriteData(0x32);                      //Set pointer
address to cursor
                  StatusCheck1();                       //location
                  WriteData(0x01);
                  StatusCheck1();
                  WriteCommand(0x24);
                  char line[] = "Reponse:   ";
                  line[1] = 0x82;          //accent aigu
                  input = getKey();       //Get user input
                  j = 20000;                    //delay before next input
                  do j--;
                  while (j!=0);
                  StatusCheck1();                        //Reset cursor
pointer address
                  WriteData(0x0a);                      //column 10
                  StatusCheck1();
                  WriteData(0x0f);                      //row 15
                  StatusCheck1();
                  WriteCommand(0x21);
                  if(input!=10){
                    j = sprintf(numberStr1,"%d",input);     //convert input
to number string
                    line[9] = numberStr1[0];
                    PrintLine(line,15);
                    number1 = atoi(numberStr1);
                    input = getKey();
                    j = 20000;                    //delay before next input
                    do j--;
                    while (j!=0);
                    i++;
                   }
                  if(input!=10){
                    j = sprintf(numberStr2,"%d",input);     //convert input
to number string
                    line[10] = numberStr2[0];
                    line[0]= 'R';                 //Reset R (Disappears,
Reason Unknown)
                    PrintLine(line,15);
                    number2 = atoi(numberStr2);
                    input = getKey();
                    j = 20000;                    //delay before next input
                    do j--;
                    while (j!=0);
                    i++;
```

```
                    }
                    if(i==0){
                      answer = 0;
                    }
                    if(i==1){
                      answer = number1;
                    }
                    else{
                      answer = 10*number1 + number2;
                    }
                    }
                           break;
            case 4: result = firstNumber * secondNumber;
/* multiplication */
                    if (result > 20 || result == 0) {              /*Account for
results greater than 20 */
                       generateNums();
                       getUserInput();
                       }
                    else {
                    DisplayMult(firstNumber,secondNumber,result);
                    WriteData(0x32);                        //Set pointer
address to cursor
                    StatusCheck1();                         //location
                    WriteData(0x01);
                    StatusCheck1();
                    WriteCommand(0x24);
                    char line[] = "Reponse:   ";
                    line[1] = 0x82;          //accent aigu
                    input = getKey();       //Get user input
                    j = 20000;                    //delay before next input
                    do j--;
                    while (j!=0);
                    StatusCheck1();                          //Reset cursor
pointer address
                    WriteData(0x0a);                        //column 10
                    StatusCheck1();
                    WriteData(0x0f);                        //row 15
                    StatusCheck1();
                    WriteCommand(0x21);
                    if(input!=10){
                      j = sprintf(numberStr1,"%d",input);     //convert input
to number string
                      line[9] = numberStr1[0];
                      PrintLine(line,15);
                      number1 = atoi(numberStr1);
                      input = getKey();
                      j = 20000;                    //delay before next input
                      do j--;
                      while (j!=0);
                      i++;
                     }
                    if(input!=10){
                      j = sprintf(numberStr2,"%d",input);     //convert input
to number string
                      line[10] = numberStr2[0];
                      line[0]= 'R';                 //Reset R (Disappears,
Reason Unknown)
                      PrintLine(line,15);
                      number2 = atoi(numberStr2);
                      input = getKey();
                      j = 20000;                    //delay before next input
                      do j--;
```

```
                    while (j!=0);
                    i++;
                  }
                  if(i==0){
                    answer = 0;
                  }
                  if(i==1){
                    answer = number1;
                  }
                  else{
                    answer = 10*number1 + number2;
                  }
                  }
                        break;
     }
     return answer;
}
int checkAnswer(int answer){
       int j;
       char numberStr[2];
       ClearScreen();
       if ((count >= 2) & (answer!=result)){                    /* Max tries
condition exceeded condition */
          problemNum++;
          totalTries++;
          count = 0;
          PrintLine("Tentatives maximums",1);
          char line1[] = "  excedees!";
          line1[5] = 0x82;
          line1[7] = 0x82;
          PrintLine(line1,2);
          char line2[]= "La reponse correcte";
          line2[4] = 0x82;
          PrintLine(line2,4);
          char line3[] = " est   .";
          j = sprintf(numberStr,"%d",result);               //j doesn't matter
          line3[6] = numberStr[0];
          if (result>=10){
              line3[7] = numberStr[1];
          }
          line3[0] = ' ';             //Disappears (Reason Unknown)
          PrintLine(line3,5);
          PrintLine("Appuyez sur n'importe", 13);
          PrintLine("quelle touche pour", 14);
          PrintLine("continuer.", 15);
          StatusCheck1();
          WriteCommand(0x94);                 //Turn Off Cursor
          StatusCheck1();
          getKey();
          return 0;
          }
       else if (answer == result){         /* Correct answer condition */
          totalTries++;
          correct++;
          count = 0;
          problemNum++;
          PrintLine("Correct!",5);
          char line[] = "Tres bien!";
          line[2] = 0x8a;
          PrintLine(line,6);
          PrintLine("Appuyez sur n'importe", 13);
          PrintLine("quelle touche pour", 14);
          PrintLine("continuer.", 15);
```

```
            StatusCheck1();
            WriteCommand(0x94);                 //Turn Off Cursor
            StatusCheck1();
            getKey();
            return 1;
            }
         else{                                /* Incorrect answer condition */
            totalTries++;
            count++;
            PrintLine("Incorrect.",5);
            PrintLine("Essayez de nouveau.",7);
            PrintLine("Appuyez sur n'importe", 13);
            PrintLine("quelle touche pour", 14);
            PrintLine("continuer.", 15);
            StatusCheck1();
            WriteCommand(0x94);                 //Turn Off Cursor
            StatusCheck1();
            getKey();
            return getUserInput();
           }
       }

void displayStats(){
      char numberStr1[2];
      char numberStr2[2];
      int j;
      ClearScreen();
      StatusCheck1();
      WriteCommand(0x94);                 //Turn Off Cursor
      StatusCheck1();
      PrintLine("Statistiques",1);
      PrintLine("Nombre de tentatives:",3);
      j = sprintf(numberStr1,"%d",totalTries);             //j doesn't matter
      PrintLine(numberStr1,4);
      PrintLine("Nombre correct:",6);
      j = sprintf(numberStr2,"%d",correct);                //j doesn't matter
      PrintLine(numberStr2,7);
      PrintLine("Appuyez sur n'importe", 13);
      PrintLine("quelle touche pour", 14);
      PrintLine("continuer.", 15);
      getKey();
      }

void clearStats(){
      count = 0;
      problemNum = 1;
      correct = 0;
      totalTries = 0;
      firstNumber = 0;
      secondNumber = 0;
      }
```

Input.c

```
#include "math.h"
#include "io430xG46x.h"

int getNumberPressed(int address){                                  //uses
decimal value to determine the number pressed on the keypad
       int x = -1;
       //returns cancel if there is some kind of error
       switch(address){
              case 9: x=1;
                              break;
```

```
                case 10: x=2;
                                break;
                case 12: x=3;
                                break;
                case 17: x=4;
                                break;
                case 18: x=5;
                                break;
                case 20: x=6;
                                break;
                case 33: x=7;
                                break;
                case 34: x=8;
                                break;
                case 36: x=9;
                                break;
                case 65: x=-1;
                                break;
                case 66: x=0;
                                break;
                case 68: x=10;
                                break;
                }
            return x;
      }
 int getKey(){
  int option;
  P2DIR = 0x07;                          //set first 3 keypad pins as outputs
  do{
    option = 0;
    unsigned char read = 0x00;
    P2OUT = 0x01;
    read = P2IN & 0x78;
    if(read != 0){                      //checks to see if key pressed is in
first column
      option = 1;
      return getNumberPressed(P2IN);
    }
    else{
      P2OUT = 0x02;
      read = P2IN & 0x78;
      if (read != 0){                   //checks to see if key pressed is in
second column
      option = 1;           //if yes passes value of P1IN to NumberSelection
      return getNumberPressed(P2IN);
      }
      else{
        P2OUT = 0x04;
        read = P2IN & 0x78;
        if (read != 0){                 //checks to see if key pressed is in
third column
          option = 1;       //if yes passes value of P1IN to NumberSelection
          return getNumberPressed(P2IN);
        }
      }
    }
 //   if((P1IN & 0x01) == 0x00){     //Exit loop for machine turnoff
 //     option = 1;
 //   }
  }//end do
  while(option == 0);
}
```

LCDControl.c

```
/* Port 4 is Data Output
   P3.0 = !WR
   P3.1 = !RD
   P3.2 = !CE
   P3.3 = C/!D
   P3.4 = !Reset
*/

#include "stdio.h"
#include "io430xG46x.h"

void StatusCheck1(){
  unsigned char busy = 0x00;
  P3DIR &= 0xe0;
  P4DIR = 0x00;                       //Reset LCD data port direction to input
  char statusCheck = P3IN;
  P3DIR |= 0x1f;
  while(busy != 0x03){
    statusCheck |=0x09;                 //!WR and C/!D high
    statusCheck &= 0xfd;                //!RD low
    P3OUT = statusCheck;                //Perform status check
    busy = (P4IN & 0x03);               //Get busy!
 //   if((P1IN & 0x01) == 0x00){          //Timeout function
 //     busy = 0x03;                      //for LCD turn off
 //   }
  }
  P4DIR = 0xff;                       //Set LCD data port back to output
}

void StatusCheck2(){
  unsigned char busy = 0x00;
  P3DIR &= 0xe0;
  P4DIR = 0x00;                       //Reset LCD data port direction to input
  char statusCheck = P3IN;
  P3DIR |= 0x1f;
  statusCheck |=0x09;                 //!WR and C/!D high
  statusCheck &= 0xfd;                //!RD low
  while(busy != 0x08){
    P3OUT = statusCheck;                        //Perform status check
    busy = (P4IN & 0x08);               //Get busy!
 //   if((P1IN & 0x01) == 0x00){          //Timeout function
 //     busy = 0x03;                     //for LCD turn off
 //   }
  }
  P4DIR = 0xff;                       //Set LCD data port back to output
}

void WriteData(unsigned char data){
  volatile unsigned int i;
  P3DIR &= 0xe0;
  char dataWrite = P3IN;
  P3DIR |= 0x1f;
  dataWrite |= 0x02;                  //Set !RD high
  dataWrite &= 0xf6;                  //Set C/!D and !WR Low
  P3OUT = dataWrite;                  //Send LCD Control
  P4OUT = data;                       //Send Data
}

void WriteCommand(unsigned char command){
  volatile unsigned int i;
  P3DIR &= 0xe0;
  char commandWrite = P3IN;
```

```
  P3DIR |= 0x1f;
  commandWrite |= 0x0a;              //Set !Rd and C/!D High
  commandWrite &= 0xfe;              //Set !WR Low
  P3OUT = commandWrite;             //Send LCD Control
  P4OUT = command;                  //Send Command
}

void PrintLine(char line[], int row){
  //row must be in the visible range (0-15)
  //line[] is a string consisting of less than 21 characters
  int i,j=0;
  char highaddress;
  if (row<12){
    highaddress = 0x00;  //Calculate correct pointer address
  }
  else {
  highaddress = 0x01;
  }

  StatusCheck1();
  WriteData(row*21);            //Set pointer address
  StatusCheck1();
  WriteData(highaddress);
  StatusCheck1();
  WriteCommand(0x24);

  StatusCheck1();                   //Set Data Autowrite mode
  WriteCommand(0xb0);

  StatusCheck1();                   //Print character array one at a time
  for(i=0;line[i]!='\0';i++){
   StatusCheck2();
   WriteData(line[i]-0x20);         //LCD character address = ASCII - 0x20
   j++;
  }

  for(i=j;i<21;i++){                //Fill remaining line with spaces
   StatusCheck2();
   WriteData(' '-0x20);
  }

  StatusCheck2();                   //End Data Autowrite
  WriteCommand(0xb2);
}

void GenerateGraphics(){

  StatusCheck1();               //Set offset register (for CGROM character
generation)
  WriteData(0x02);              //corresponds to address 00010 1000000 000 =
0x1400
  StatusCheck1();
  WriteData(0x00);
  StatusCheck1();
  WriteCommand(0x22);

  //Person
  StatusCheck1();               //Set address pointer (for CGROM character
generation)
  WriteData(0x00);
  StatusCheck1();
  WriteData(0x14);              //0x1400 corresponds to character code 0x80
  StatusCheck1();
```

```
  WriteCommand(0x24);

  StatusCheck1();             //Set Data Autowrite
  WriteCommand(0xb0);

  StatusCheck1();             //Generate upper left person
  StatusCheck2();
  WriteData(0x00);
  StatusCheck2();
  WriteData(0x03);
  StatusCheck2();
  WriteData(0x07);
  StatusCheck2();
  WriteData(0x07);
  StatusCheck2();
  WriteData(0x07);
  StatusCheck2();
  WriteData(0x03);
  StatusCheck2();
  WriteData(0x01);
  StatusCheck2();
  WriteData(0x03);

  StatusCheck2();             //End Data Autowrite
  WriteCommand(0xb2);

  StatusCheck1();            //Set address pointer (for CGROM character
generation)
  WriteData(0x08);
  StatusCheck1();
  WriteData(0x14);           //0x1408 corresponds to character code 0x81
  StatusCheck1();
  WriteCommand(0x24);

  StatusCheck1();             //Set Data Autowrite
  WriteCommand(0xb0);

  StatusCheck1();             //Generate upper right person
  StatusCheck2();
  WriteData(0x00);
  StatusCheck2();
  WriteData(0x30);
  StatusCheck2();
  WriteData(0x38);
  StatusCheck2();
  WriteData(0x38);
  StatusCheck2();
  WriteData(0x38);
  StatusCheck2();
  WriteData(0x30);
  StatusCheck2();
  WriteData(0x20);
  StatusCheck2();
  WriteData(0x30);

  StatusCheck2();             //End Data Autowrite
  WriteCommand(0xb2);

  StatusCheck1();               //Set address pointer (for CGROM character
generation)
  WriteData(0x10);
  StatusCheck1();
  WriteData(0x14);              //0x1410 corresponds to character code 0x82
```

```
  StatusCheck1();
  WriteCommand(0x24);

  StatusCheck1();             //Set Data Autowrite
  WriteCommand(0xb0);

  StatusCheck1();             //Generate lower left person
  StatusCheck2();
  WriteData(0x05);
  StatusCheck2();
  WriteData(0x09);
  StatusCheck2();
  WriteData(0x01);
  StatusCheck2();
  WriteData(0x01);
  StatusCheck2();
  WriteData(0x01);
  StatusCheck2();
  WriteData(0x02);
  StatusCheck2();
  WriteData(0x0c);
  StatusCheck2();
  WriteData(0x00);

  StatusCheck2();             //End Data Autowrite
  WriteCommand(0xb2);

  StatusCheck1();               //Set address pointer (for CGROM character
generation)
  WriteData(0x18);
  StatusCheck1();
  WriteData(0x14);              //0x1418 corresponds to character code 0x83
  StatusCheck1();
  WriteCommand(0x24);

  StatusCheck1();             //Set Data Autowrite
  WriteCommand(0xb0);

  StatusCheck1();             //Generate lower right person
  StatusCheck2();
  WriteData(0x28);
  StatusCheck2();
  WriteData(0x24);
  StatusCheck2();
  WriteData(0x20);
  StatusCheck2();
  WriteData(0x20);
  StatusCheck2();
  WriteData(0x20);
  StatusCheck2();
  WriteData(0x10);
  StatusCheck2();
  WriteData(0x0c);
  StatusCheck2();
  WriteData(0x00);

  StatusCheck2();             //End Data Autowrite
  WriteCommand(0xb2);

  //Ladybug
  StatusCheck1();               //Set address pointer (for CGROM character
generation)
  WriteData(0x20);
```

```
  StatusCheck1();
  WriteData(0x14);              //0x1400 corresponds to character code 0x84
  StatusCheck1();
  WriteCommand(0x24);

  StatusCheck1();             //Set Data Autowrite
  WriteCommand(0xb0);

  StatusCheck1();             //Generate upper left ladybug
  StatusCheck2();
  WriteData(0x04);
  StatusCheck2();
  WriteData(0x02);
  StatusCheck2();
  WriteData(0x01);
  StatusCheck2();
  WriteData(0x03);
  StatusCheck2();
  WriteData(0x03);
  StatusCheck2();
  WriteData(0x04);
  StatusCheck2();
  WriteData(0x09);
  StatusCheck2();
  WriteData(0x09);

  StatusCheck2();             //End Data Autowrite
  WriteCommand(0xb2);

  StatusCheck1();            //Set address pointer (for CGROM character
generation)
  WriteData(0x28);
  StatusCheck1();
  WriteData(0x14);           //0x1428 corresponds to character code 0x85
  StatusCheck1();
  WriteCommand(0x24);

  StatusCheck1();             //Set Data Autowrite
  WriteCommand(0xb0);

  StatusCheck1();             //Generate upper right ladybug
  StatusCheck2();
  WriteData(0x08);
  StatusCheck2();
  WriteData(0x10);
  StatusCheck2();
  WriteData(0x20);
  StatusCheck2();
  WriteData(0x30);
  StatusCheck2();
  WriteData(0x30);
  StatusCheck2();
  WriteData(0x08);
  StatusCheck2();
  WriteData(0x24);
  StatusCheck2();
  WriteData(0x24);

  StatusCheck2();             //End Data Autowrite
  WriteCommand(0xb2);

  StatusCheck1();               //Set address pointer (for CGROM character
generation)
```

```
  WriteData(0x30);
  StatusCheck1();
  WriteData(0x14);              //0x1430 corresponds to character code 0x86
  StatusCheck1();
  WriteCommand(0x24);

  StatusCheck1();             //Set Data Autowrite
  WriteCommand(0xb0);

  StatusCheck1();             //Generate lower left ladybug
  StatusCheck2();
  WriteData(0x10);
  StatusCheck2();
  WriteData(0x16);
  StatusCheck2();
  WriteData(0x12);
  StatusCheck2();
  WriteData(0x08);
  StatusCheck2();
  WriteData(0x09);
  StatusCheck2();
  WriteData(0x04);
  StatusCheck2();
  WriteData(0x03);
  StatusCheck2();
  WriteData(0x00);

  StatusCheck2();             //End Data Autowrite
  WriteCommand(0xb2);

  StatusCheck1();               //Set address pointer (for CGROM character
generation)
  WriteData(0x38);
  StatusCheck1();
  WriteData(0x14);              //0x1438 corresponds to character code 0x87
  StatusCheck1();
  WriteCommand(0x24);

  StatusCheck1();             //Set Data Autowrite
  WriteCommand(0xb0);

  StatusCheck1();             //Generate lower right ladybug
  StatusCheck2();
  WriteData(0x02);
  StatusCheck2();
  WriteData(0x1a);
  StatusCheck2();
  WriteData(0x12);
  StatusCheck2();
  WriteData(0x04);
  StatusCheck2();
  WriteData(0x24);
  StatusCheck2();
  WriteData(0x08);
  StatusCheck2();
  WriteData(0x30);
  StatusCheck2();
  WriteData(0x00);

  StatusCheck2();             //End Data Autowrite
  WriteCommand(0xb2);

  //Generate X
```

```
  StatusCheck1();               //Set address pointer (for CGROM character
generation)
  WriteData(0x40);
  StatusCheck1();
  WriteData(0x14);              //0x1440 corresponds to character code 0x88
  StatusCheck1();
  WriteCommand(0x24);

  StatusCheck1();             //Set Data Autowrite
  WriteCommand(0xb0);

  StatusCheck1();             //Generate upper left X
  StatusCheck2();
  WriteData(0x00);
  StatusCheck2();
  WriteData(0x10);
  StatusCheck2();
  WriteData(0x10);
  StatusCheck2();
  WriteData(0x08);
  StatusCheck2();
  WriteData(0x04);
  StatusCheck2();
  WriteData(0x04);
  StatusCheck2();
  WriteData(0x02);
  StatusCheck2();
  WriteData(0x01);

  StatusCheck2();             //End Data Autowrite
  WriteCommand(0xb2);

  StatusCheck1();            //Set address pointer (for CGROM character
generation)
  WriteData(0x48);
  StatusCheck1();
  WriteData(0x14);           //0x1448 corresponds to character code 0x89
  StatusCheck1();
  WriteCommand(0x24);

  StatusCheck1();             //Set Data Autowrite
  WriteCommand(0xb0);

  StatusCheck1();             //Generate upper right X
  StatusCheck2();
  WriteData(0x00);
  StatusCheck2();
  WriteData(0x02);
  StatusCheck2();
  WriteData(0x02);
  StatusCheck2();
  WriteData(0x04);
  StatusCheck2();
  WriteData(0x08);
  StatusCheck2();
  WriteData(0x08);
  StatusCheck2();
  WriteData(0x10);
  StatusCheck2();
  WriteData(0x20);

  StatusCheck2();             //End Data Autowrite
  WriteCommand(0xb2);
```

```
  StatusCheck1();               //Set address pointer (for CGROM character
generation)
  WriteData(0x50);
  StatusCheck1();
  WriteData(0x14);              //0x1450 corresponds to character code 0x8a
  StatusCheck1();
  WriteCommand(0x24);

  StatusCheck1();             //Set Data Autowrite
  WriteCommand(0xb0);

  StatusCheck1();             //Generate lower left X
  StatusCheck2();
  WriteData(0x01);
  StatusCheck2();
  WriteData(0x02);
  StatusCheck2();
  WriteData(0x04);
  StatusCheck2();
  WriteData(0x04);
  StatusCheck2();
  WriteData(0x08);
  StatusCheck2();
  WriteData(0x10);
  StatusCheck2();
  WriteData(0x10);
  StatusCheck2();
  WriteData(0x00);

  StatusCheck2();             //End Data Autowrite
  WriteCommand(0xb2);

  StatusCheck1();               //Set address pointer (for CGROM character
generation)
  WriteData(0x58);
  StatusCheck1();
  WriteData(0x14);              //0x1458 corresponds to character code 0x8b
  StatusCheck1();
  WriteCommand(0x24);

  StatusCheck1();             //Set Data Autowrite
  WriteCommand(0xb0);

  StatusCheck1();             //Generate lower right X
  StatusCheck2();
  WriteData(0x20);
  StatusCheck2();
  WriteData(0x10);
  StatusCheck2();
  WriteData(0x08);
  StatusCheck2();
  WriteData(0x08);
  StatusCheck2();
  WriteData(0x04);
  StatusCheck2();
  WriteData(0x02);
  StatusCheck2();
  WriteData(0x02);
  StatusCheck2();
  WriteData(0x00);

  StatusCheck2();             //End Data Autowrite
```

```
  WriteCommand(0xb2);

  //Stick
  StatusCheck1();            //Set address pointer (for CGROM character
generation)
  WriteData(0x60);
  StatusCheck1();
  WriteData(0x14);           //0x1460 corresponds to character code 0x8c
  StatusCheck1();
  WriteCommand(0x24);

  StatusCheck1();             //Set Data Autowrite
  WriteCommand(0xb0);

  StatusCheck1();             //Generate left stick
  StatusCheck2();
  WriteData(0x00);
  StatusCheck2();
  WriteData(0x10);
  StatusCheck2();
  WriteData(0x18);
  StatusCheck2();
  WriteData(0x1f);
  StatusCheck2();
  WriteData(0x1f);
  StatusCheck2();
  WriteData(0x18);
  StatusCheck2();
  WriteData(0x10);
  StatusCheck2();
  WriteData(0x00);

  StatusCheck2();             //End Data Autowrite
  WriteCommand(0xb2);

  StatusCheck1();               //Set address pointer (for CGROM character
generation)
  WriteData(0x68);
  StatusCheck1();
  WriteData(0x14);              //0x1468 corresponds to character code 0x8d
  StatusCheck1();
  WriteCommand(0x24);

  StatusCheck1();             //Set Data Autowrite
  WriteCommand(0xb0);

  StatusCheck1();             //Generate middle stick
  StatusCheck2();
  WriteData(0x00);
  StatusCheck2();
  WriteData(0x02);
  StatusCheck2();
  WriteData(0x04);
  StatusCheck2();
  WriteData(0x3f);
  StatusCheck2();
  WriteData(0x3f);
  StatusCheck2();
  WriteData(0x20);
  StatusCheck2();
  WriteData(0x10);
  StatusCheck2();
  WriteData(0x00);
```

```
  StatusCheck2();             //End Data Autowrite
  WriteCommand(0xb2);

  StatusCheck1();               //Set address pointer (for CGROM character
generation)
  WriteData(0x70);
  StatusCheck1();
  WriteData(0x14);              //0x1470 corresponds to character code 0x8e
  StatusCheck1();
  WriteCommand(0x24);

  StatusCheck1();             //Set Data Autowrite
  WriteCommand(0xb0);

  StatusCheck1();             //Generate right stick
  StatusCheck2();
  WriteData(0x00);
  StatusCheck2();
  WriteData(0x00);
  StatusCheck2();
  WriteData(0x10);
  StatusCheck2();
  WriteData(0x20);
  StatusCheck2();
  WriteData(0x3e);
  StatusCheck2();
  WriteData(0x10);
  StatusCheck2();
  WriteData(0x08);
  StatusCheck2();
  WriteData(0x00);

  StatusCheck2();             //End Data Autowrite
  WriteCommand(0xb2);

  //Fish
  StatusCheck1();               //Set address pointer (for CGROM character
generation)
  WriteData(0x78);
  StatusCheck1();
  WriteData(0x14);              //0x1478 corresponds to character code 0x8f
  StatusCheck1();
  WriteCommand(0x24);

  StatusCheck1();             //Set Data Autowrite
  WriteCommand(0xb0);

  StatusCheck1();             //Generate left fish
  StatusCheck2();
  WriteData(0x00);
  StatusCheck2();
  WriteData(0x10);
  StatusCheck2();
  WriteData(0x18);
  StatusCheck2();
  WriteData(0x1d);
  StatusCheck2();
  WriteData(0x1f);
  StatusCheck2();
  WriteData(0x1d);
  StatusCheck2();
  WriteData(0x18);
```

```
  StatusCheck2();
  WriteData(0x10);

  StatusCheck2();             //End Data Autowrite
  WriteCommand(0xb2);

  StatusCheck1();               //Set address pointer (for CGROM character
generation)
  WriteData(0x80);
  StatusCheck1();
  WriteData(0x14);              //0x1480 corresponds to character code 0x90
  StatusCheck1();
  WriteCommand(0x24);

  StatusCheck1();             //Set Data Autowrite
  WriteCommand(0xb0);

  StatusCheck1();             //Generate right fish
  StatusCheck2();
  WriteData(0x00);
  StatusCheck2();
  WriteData(0x1c);
  StatusCheck2();
  WriteData(0x3e);
  StatusCheck2();
  WriteData(0x3f);
  StatusCheck2();
  WriteData(0x3f);
  StatusCheck2();
  WriteData(0x3f);
  StatusCheck2();
  WriteData(0x3e);
  StatusCheck2();
  WriteData(0x1c);

  StatusCheck2();             //End Data Autowrite
  WriteCommand(0xb2);

  //Bowl
  StatusCheck1();               //Set address pointer (for CGROM character
generation)
  WriteData(0x88);
  StatusCheck1();
  WriteData(0x14);              //0x1488 corresponds to character code 0x91
  StatusCheck1();
  WriteCommand(0x24);

  StatusCheck1();             //Set Data Autowrite
  WriteCommand(0xb0);

  StatusCheck1();             //Generate left bowl
  StatusCheck2();
  WriteData(0x00);
  StatusCheck2();
  WriteData(0x1f);
  StatusCheck2();
  WriteData(0x0f);
  StatusCheck2();
  WriteData(0x07);
  StatusCheck2();
  WriteData(0x03);
  StatusCheck2();
  WriteData(0x01);
```

```
  StatusCheck2();
  WriteData(0x00);
  StatusCheck2();
  WriteData(0x00);

  StatusCheck2();             //End Data Autowrite
  WriteCommand(0xb2);

  StatusCheck1();               //Set address pointer (for CGROM character
generation)
  WriteData(0x90);
  StatusCheck1();
  WriteData(0x14);              //0x1490 corresponds to character code 0x92
  StatusCheck1();
  WriteCommand(0x24);

  StatusCheck1();             //Set Data Autowrite
  WriteCommand(0xb0);

  StatusCheck1();             //Generate middle bowl
  StatusCheck2();
  WriteData(0x00);
  StatusCheck2();
  WriteData(0x3f);
  StatusCheck2();
  WriteData(0x3f);
  StatusCheck2();
  WriteData(0x3f);
  StatusCheck2();
  WriteData(0x00);
  StatusCheck2();
  WriteData(0x3f);
  StatusCheck2();
  WriteData(0x3f);
  StatusCheck2();
  WriteData(0x00);

  StatusCheck2();             //End Data Autowrite
  WriteCommand(0xb2);

  StatusCheck1();               //Set address pointer (for CGROM character
generation)
  WriteData(0x98);
  StatusCheck1();
  WriteData(0x14);              //0x1498 corresponds to character code 0x93
  StatusCheck1();
  WriteCommand(0x24);

  StatusCheck1();             //Set Data Autowrite
  WriteCommand(0xb0);

  StatusCheck1();             //Generate right bowl
  StatusCheck2();
  WriteData(0x00);
  StatusCheck2();
  WriteData(0x3e);
  StatusCheck2();
  WriteData(0x3c);
  StatusCheck2();
  WriteData(0x38);
  StatusCheck2();
  WriteData(0x30);
  StatusCheck2();
```

```
  WriteData(0x20);
  StatusCheck2();
  WriteData(0x00);
  StatusCheck2();
  WriteData(0x00);

  StatusCheck2();             //End Data Autowrite
  WriteCommand(0xb2);
}

void ClearScreen(){
  unsigned int i = 337;

  //Write to screen
  StatusCheck1();               //Set address pointer to home address
  WriteData(0x00);
  StatusCheck1();
  WriteData(0x00);
  StatusCheck1();
  WriteCommand(0x24);

  StatusCheck1();             //Set Data Autowrite
  WriteCommand(0xb0);

  do{
  StatusCheck2();             //Clear Screen by filling with spaces
  WriteData(' '-0x20);
  i--;
  }
  while(i>0);

  StatusCheck2();             //End Data Autowrite
  WriteCommand(0xb2);
}

void DisplayAddition(int firstnum, int secondnum, int result){

  int i;
  char numberStr1[2];
  char numberStr2[2];

  //Make sure larger number is first for display purposes
  if(secondnum > firstnum){
    i= secondnum;
    secondnum = firstnum;
    firstnum = i;
  }

  ClearScreen();

  char line1[] = "S'il y a    personnes";
  i = sprintf(numberStr1,"%d",firstnum);               //i doesn't matter
  line1[9] = numberStr1[0];
  if (firstnum>=10){
    line1[10] = numberStr1[1];
  }
  PrintLine(line1,0);
  char line2[] = "au marche, et    pers";
  i = sprintf(numberStr2,"%d",secondnum);
  line2[8] = 0x82;                                  //Corresponds to accent aigu
  line2[14] = numberStr2[0];
  if (secondnum>=10){
    line2[15] = numberStr2[1];
```

```
}
PrintLine(line2,1);
PrintLine("onnes les rejoignent,",2);
PrintLine("combien de personnes",3);
char line3[] = "sont au marche?";
line3[13] = 0x82;
PrintLine(line3,4);
char line4[] = "Reponse: ";
line4[1] = 0x82;
PrintLine(line4,14);

StatusCheck1();
WriteData(0x7e);                        //Set pointer address to line 6
StatusCheck1();                         //6*21 = 126
WriteData(0x00);
StatusCheck1();
WriteCommand(0x24);
StatusCheck1();


for(i=0;i<firstnum;i++){
  StatusCheck1();                        //Generate upper person
  WriteData(0x80);
  StatusCheck1();
  WriteCommand(0xc0);

  StatusCheck1();
  WriteData(0x81);
  StatusCheck1();
  WriteCommand(0xc0);

  if (i==9){
    StatusCheck1();
    WriteData(0xa8);                     //Reset pointer address
    StatusCheck1();                      //to line 8
    WriteData(0x00);
    StatusCheck1();
    WriteCommand(0x24);
  }
}

  StatusCheck1();
  WriteData(0x93);                       //Reset pointer address
  StatusCheck1();                        //to line 7
  WriteData(0x00);
  StatusCheck1();
  WriteCommand(0x24);

  for(int i=0;i<firstnum;i++){
  StatusCheck1();                        //Generate lower person
  WriteData(0x82);
  StatusCheck1();
  WriteCommand(0xc0);

  StatusCheck1();
  WriteData(0x83);
  StatusCheck1();
  WriteCommand(0xc0);

  if (i==9){
    StatusCheck1();
    WriteData(0xbd);                     //Reset pointer address
    StatusCheck1();                      //to line 9
```

```
    WriteData(0x00);
    StatusCheck1();
    WriteCommand(0x24);
  }
}

StatusCheck1();
WriteData(0xd3);                        //Reset pointer address
StatusCheck1();                         //to line 10 + 1 column
WriteData(0x00);
StatusCheck1();
WriteCommand(0x24);

StatusCheck1();                        //Generate addition sign
WriteData('+'-0x20);
StatusCheck1();
WriteCommand(0xc0);

StatusCheck1();
WriteData(0xe7);                        //Reset pointer address
StatusCheck1();                         //to line 11
WriteData(0x00);
StatusCheck1();
WriteCommand(0x24);
StatusCheck1();

for(int i=0;i<secondnum;i++){
  StatusCheck1();                        //Generate upper person
  WriteData(0x80);
  StatusCheck1();
  WriteCommand(0xc0);

  StatusCheck1();
  WriteData(0x81);
  StatusCheck1();
  WriteCommand(0xc0);
}

StatusCheck1();
WriteData(0xfc);                        //Reset pointer address
StatusCheck1();                         //to line 12
WriteData(0x00);
StatusCheck1();
WriteCommand(0x24);
StatusCheck1();

for(int i=0;i<secondnum;i++){
StatusCheck1();                        //Generate lower person
WriteData(0x82);
StatusCheck1();
WriteCommand(0xc0);

StatusCheck1();
WriteData(0x83);
StatusCheck1();
WriteCommand(0xc0);
}

StatusCheck1();                         //Set cursor pointer address
WriteData(0x09);                        //column 8
StatusCheck1();
WriteData(0x0e);                        //row 14
StatusCheck1();
```

```
  WriteCommand(0x21);

  StatusCheck1();
  WriteCommand(0x97);                  //Turn cursor on
  StatusCheck1();
}

void DisplaySubtraction(int firstnum, int secondnum, int result){

  ClearScreen();

  int i;
  char numberStr1[2];
  char numberStr2[2];

  char line1[] = "S'il y a   ";
  i = sprintf(numberStr1,"%d",firstnum);               //i doesn't matter
  line1[9] = numberStr1[0];
  if (firstnum>=10){
    line1[10] = numberStr1[1];
  }
  PrintLine(line1,0);
  PrintLine("coccinelles sur une",1);
  char line2[] = "branche, et   ";
  i = sprintf(numberStr2,"%d",secondnum);               //i doesn't matter
  line2[12] = numberStr2[0];
  if (secondnum>=10){
    line2[13] = numberStr2[1];
  }
  PrintLine(line2,2);
  PrintLine("s'envolent, combien",3);
  PrintLine("reste-t-il?",4);
  char line3[] = "Reponse: ";
  line3[1] = 0x82;
  PrintLine(line3,13);

  //Generate Ladybugs
  StatusCheck1();
  WriteData(0x7e);                        //Set pointer address to line 6
  StatusCheck1();                         //6*21 = 126
  WriteData(0x00);
  StatusCheck1();
  WriteCommand(0x24);

  for(i=0;i<firstnum;i++){
    StatusCheck1();                        //Generate upper ladybug
    WriteData(0x84);
    StatusCheck1();
    WriteCommand(0xc0);

    StatusCheck1();
    WriteData(0x85);
    StatusCheck1();
    WriteCommand(0xc0);

    if (i==9){
      StatusCheck1();
      WriteData(0xa8);                     //Reset pointer address
      StatusCheck1();                      //to line 8
      WriteData(0x00);
      StatusCheck1();
      WriteCommand(0x24);
    }
```

```
}

StatusCheck1();
WriteData(0x93);                    //Reset pointer address
StatusCheck1();                     //to line 7
WriteData(0x00);
StatusCheck1();
WriteCommand(0x24);

for(int i=0;i<firstnum;i++){
StatusCheck1();                       //Generate lower ladybug
WriteData(0x86);
StatusCheck1();
WriteCommand(0xc0);

StatusCheck1();
WriteData(0x87);
StatusCheck1();
WriteCommand(0xc0);

if (i==9){
    StatusCheck1();
    WriteData(0xbd);                    //Reset pointer address
    StatusCheck1();                     //to line 9
    WriteData(0x00);
    StatusCheck1();
    WriteCommand(0x24);
  }
}

//Generate Xs
StatusCheck1();
WriteData(0x7e);                      //Set pointer address to line 6
StatusCheck1();                       //6*21 = 126
WriteData(0x00);
StatusCheck1();
WriteCommand(0x24);

for(i=0;i<secondnum;i++){
  StatusCheck1();                      //Generate upper X
  WriteData(0x88);
  StatusCheck1();
  WriteCommand(0xc0);

  StatusCheck1();
  WriteData(0x89);
  StatusCheck1();
  WriteCommand(0xc0);

  if (i==9){
    StatusCheck1();
    WriteData(0xa8);                    //Reset pointer address
    StatusCheck1();                     //to line 8
    WriteData(0x00);
    StatusCheck1();
    WriteCommand(0x24);
  }
}

StatusCheck1();
WriteData(0x93);                    //Reset pointer address
StatusCheck1();                     //to line 7
WriteData(0x00);
```

```
  StatusCheck1();
  WriteCommand(0x24);

  for(i=0;i<secondnum;i++){
  StatusCheck1();                         //Generate lower X
  WriteData(0x8a);
  StatusCheck1();
  WriteCommand(0xc0);

  StatusCheck1();
  WriteData(0x8b);
  StatusCheck1();
  WriteCommand(0xc0);

  if (i==9){
      StatusCheck1();
      WriteData(0xbd);                     //Reset pointer address
      StatusCheck1();                      //to line 9
      WriteData(0x00);
      StatusCheck1();
      WriteCommand(0x24);
    }
  }

  StatusCheck1();                          //Set cursor pointer address
  WriteData(0x09);                        //column 8
  StatusCheck1();
  WriteData(0x0d);                        //row 13
  StatusCheck1();
  WriteCommand(0x21);

  StatusCheck1();
  WriteCommand(0x97);                 //Turn cursor on
  StatusCheck1();
}

void DisplayMult(int firstnum, int secondnum, int result){

  int i,j,charcount=0;
  int overflow=0;
  int ladybugcount = 0;
  int groupcount = 0;
  char numberStr1[2];
  char numberStr2[2];

  ClearScreen();

  //Do not let second number be greater than 10
  //to avoid stick overflow
  if(secondnum>10){
    i = secondnum;
    secondnum = firstnum;
    firstnum = i;
  }

  char line1[] = "Si on a    rameux, et";
  i = sprintf(numberStr1,"%d",firstnum);                //i doesn't matter
  line1[8] = numberStr1[0];
  if (firstnum>=10){
    line1[9] = numberStr1[1];
  }
  PrintLine(line1,0);
  char line2[] = "il y a    coccinelles";
```

```
i = sprintf(numberStr2,"%d",secondnum);                //i doesn't matter
line2[7] = numberStr2[0];
if (secondnum>=10){
  line2[8] = numberStr2[1];
}
PrintLine(line2,1);
PrintLine("sur chaque rameau,",2);
PrintLine("combien de ",3);
PrintLine("coccinelles a-t-on?",4);
char line3[] = "Reponse: ";
line3[1] = 0x82;
PrintLine(line3,15);

StatusCheck1();
WriteData(0x7e);                        //Set pointer address to line 6
StatusCheck1();
WriteData(0x00);
StatusCheck1();
WriteCommand(0x24);
StatusCheck1();

for(i=0;i<result;i++){
  StatusCheck1();                        //Generate upper ladybug
  WriteData(0x84);
  StatusCheck1();
  WriteCommand(0xc0);

  StatusCheck1();
  WriteData(0x85);
  StatusCheck1();
  WriteCommand(0xc0);
  ladybugcount++;
  groupcount++;

  if(groupcount==secondnum){           //Check for fit of next group
    if((10-ladybugcount)<secondnum){    //If full group will not fit...
      if(overflow == 0){
        StatusCheck1();
        WriteData(0xbd);                       //...Reset pointer address
        StatusCheck1();                        //to line 9 the first time
        WriteData(0x00);
        StatusCheck1();
        WriteCommand(0x24);
        StatusCheck1();
        overflow++;
        ladybugcount=0;                        //reset ladybug count
      } else{
          StatusCheck1();
          WriteData(0xfc);                       //...Reset pointer address
          StatusCheck1();                        //to line 12 the second time
          WriteData(0x00);
          StatusCheck1();
          WriteCommand(0x24);
          StatusCheck1();
        }
    }
    groupcount = 0;                           //reset groupcount
  }
}

StatusCheck1();
WriteData(0x93);                        //Reset pointer address
StatusCheck1();                         //to line 7
```

```
WriteData(0x00);
StatusCheck1();
WriteCommand(0x24);
StatusCheck1();

groupcount = 0;                          //reinitialize
ladybugcount = 0;
overflow = 0;

for(i=0;i<result;i++){
  StatusCheck1();                         //Generate lower ladybug
  WriteData(0x86);
  StatusCheck1();
  WriteCommand(0xc0);

  StatusCheck1();
  WriteData(0x87);
  StatusCheck1();
  WriteCommand(0xc0);
  ladybugcount++;
  groupcount++;

  if(groupcount==secondnum){            //Check for fit of next group
    if((10-ladybugcount)<secondnum){    //If full group will not fit...
      if(overflow == 0){
        StatusCheck1();
        WriteData(0xd2);                        //...Reset pointer address
        StatusCheck1();                         //to line 10 the first time
        WriteData(0x00);
        StatusCheck1();
        WriteCommand(0x24);
        StatusCheck1();
        overflow++;
        ladybugcount=0;                         //reset ladybug count
      } else{
          StatusCheck1();
          WriteData(0x11);                        //...Reset pointer address
          StatusCheck1();                         //to line 13 the second time
          WriteData(0x01);
          StatusCheck1();
          WriteCommand(0x24);
          StatusCheck1();
          }
    }
    groupcount = 0;                             //reset groupcount
  }
}

overflow = 0;                             //Re-initialize

StatusCheck1();
WriteData(0xa8);                          //Reset pointer address
StatusCheck1();                           //to line 8
WriteData(0x00);
StatusCheck1();
WriteCommand(0x24);
StatusCheck1();

for(i=0;i<firstnum;i++){
  for(j=1;j<=(2*secondnum);j++){
    if(j==1){
      StatusCheck1();                         //Generate left stick
      WriteData(0x8c);
```

```
        StatusCheck1();
        WriteCommand(0xc0);
      } else if(j==(2*secondnum)){                //Generate right stick
        StatusCheck1();
        WriteData(0x8e);
        StatusCheck1();
        WriteCommand(0xc0);
          if((20-charcount)<(2*secondnum)){     //If not enough spaces for next
stick...
            if(overflow==0){
              StatusCheck1();
              WriteData(0xe7);                  //...Reset pointer address
              StatusCheck1();                   //to line 11 the first time
              WriteData(0x00);
              StatusCheck1();
              WriteCommand(0x24);
              StatusCheck1();
              overflow++;                       //one overflow has ocurred
              charcount=0;                      //reset character count
            } else{
              StatusCheck1();
              WriteData(0x26);                  //...Reset pointer address
              StatusCheck1();                   //to line 14 the second time
              WriteData(0x01);
              StatusCheck1();
              WriteCommand(0x24);
              StatusCheck1();
              }
          }
        } else{
          StatusCheck1();                       //Generate middle stick
          WriteData(0x8d);
          StatusCheck1();
          WriteCommand(0xc0);
          }
      charcount++;
    }
  }

  StatusCheck1();                           //Set cursor pointer address
  WriteData(0x09);                         //column 8
  StatusCheck1();
  WriteData(0x0f);                         //row 15
  StatusCheck1();
  WriteCommand(0x21);

  StatusCheck1();
  WriteCommand(0x97);                 //Turn cursor on
  StatusCheck1();
}

void DisplayDiv(int firstnum, int secondnum, int result){

  int i,j,charcount=0;
  int overflow=0;
  int fishcount = 0;
  int groupcount = 0;
  char numberStr1[2];
  char numberStr2[2];

  ClearScreen();

  //Do not let result be greater than 10!!!!!!!!!!!!!!!!!!!!!
```

```
//to avoid bowl overflow   (Handle in main program)!!!!!!!!!

char line1[] = "Si on a    poissons,";
i = sprintf(numberStr1,"%d",firstnum);             //i doesn't matter
line1[8] = numberStr1[0];
if (firstnum>=10){
  line1[9] = numberStr1[1];
}
PrintLine(line1,0);
PrintLine("et on les divise",1);
char line2[] = "egalement entre   ";
i = sprintf(numberStr2,"%d",secondnum);             //i doesn't matter
line2[16] = numberStr2[0];
if (secondnum>=10){
  line2[17] = numberStr2[1];
}
line2[0] = 0x82;                              //correspondes to accent aigu
PrintLine(line2,2);
PrintLine("bocaux, combien de",3);
PrintLine("poissons sont dans",4);
PrintLine("chaque bocal?",5);
char line3[] = "Reponse: ";
line3[1] = 0x82;
PrintLine(line3,15);

StatusCheck1();
WriteData(0x7e);                         //Set pointer address to line 6
StatusCheck1();
WriteData(0x00);
StatusCheck1();
WriteCommand(0x24);
StatusCheck1();
WriteData(0x7e);                         //Set pointer address to line 6
StatusCheck1();
WriteData(0x00);
StatusCheck1();
WriteCommand(0x24);
StatusCheck1();

for(i=0;i<firstnum;i++){
  StatusCheck1();                         //Generate left fish
  WriteData(0x8f);
  StatusCheck1();
  WriteCommand(0xc0);

  StatusCheck1();                         //Generate right fish
  WriteData(0x90);
  StatusCheck1();
  WriteCommand(0xc0);
  fishcount++;
  groupcount++;

  if(groupcount==result){           //Check for fit of next group
    if((10-fishcount)<result){    //If full group will not fit...
      if(overflow == 0){
        StatusCheck1();
        WriteData(0xbd);                        //...Reset pointer address
        StatusCheck1();                         //to line 9 the first time
        WriteData(0x00);
        StatusCheck1();
        WriteCommand(0x24);
        StatusCheck1();
        overflow++;
```

```
          fishcount=0;                          //reset fish count
        } else{
            StatusCheck1();
            WriteData(0xfc);                        //...Reset pointer address
            StatusCheck1();                         //to line 12 the second time
            WriteData(0x00);
            StatusCheck1();
            WriteCommand(0x24);
            StatusCheck1();
          }
      }
      groupcount = 0;                           //reset groupcount
    }
  }

  overflow = 0;                             //Re-initialize

  StatusCheck1();
  WriteData(0x93);                          //Reset pointer address
  StatusCheck1();                           //to line 7
  WriteData(0x00);
  StatusCheck1();
  WriteCommand(0x24);
  StatusCheck1();

  for(i=0;i<secondnum;i++){
    for(j=1;j<=(2*result);j++){
      if(j==1){
        StatusCheck1();                         //Generate left bowl
        WriteData(0x91);
        StatusCheck1();
        WriteCommand(0xc0);
      } else if(j==(2*result)){                 //Generate right bowl
        StatusCheck1();
        WriteData(0x93);
        StatusCheck1();
        WriteCommand(0xc0);
          if((20-charcount)<(2*result)){     //If not enough spaces for next
bowl...
            if(overflow==0){
              StatusCheck1();
              WriteData(0xd2);                  //...Reset pointer address
              StatusCheck1();                   //to line 10 the first time
              WriteData(0x00);
              StatusCheck1();
              WriteCommand(0x24);
              StatusCheck1();
              overflow++;                       //one overflow has ocurred
              charcount=0;                      //reset character count
            } else{
              StatusCheck1();
              WriteData(0x11);                  //...Reset pointer address
              StatusCheck1();                   //to line 13 the second time
              WriteData(0x01);
              StatusCheck1();
              WriteCommand(0x24);
              StatusCheck1();
              }
          }
        } else{
          StatusCheck1();                       //Generate middle bowl
          WriteData(0x92);
          StatusCheck1();
```

```
          WriteCommand(0xc0);
          }
       charcount++;
     }
   }

   StatusCheck1();                          //Set cursor pointer address
   WriteData(0x09);                         //column 8
   StatusCheck1();
   WriteData(0x0f);                         //row 15
   StatusCheck1();
   WriteCommand(0x21);

   StatusCheck1();
   WriteCommand(0x97);
   StatusCheck1();
}

void InitializeLCD(void)
{
   volatile unsigned int i;            // volatile to prevent optimization

   P4DIR = 0xff;                        // Set Port 4 to output direction
   P3DIR |= 0x1f;                       // Set select Port 3 pins to output

   //LCD Initialize
   P3OUT &= 0xfb;                       //Turn on Chip Enable
   P3OUT &= 0xef;                       //Keep Reset low for at least five
clock cycles
   i = 50;
   do i--;
   while (i!=0);
   P3OUT |= 0x10;                       //Put reset high again
   i = 10;
   do i--;
   while (i!=0);

   //Send Commands
   StatusCheck1();
   WriteCommand(0x80);                  //Set OR mode

   StatusCheck1();
   WriteData(0x00);                     //Set text home address
   StatusCheck1();
   WriteData(0x00);
   StatusCheck1();
   WriteCommand(0x40);

   StatusCheck1();
   WriteData(0x15);                     //Set text area
   StatusCheck1();
   WriteData(0x00);
   StatusCheck1();
   WriteCommand(0x41);

   StatusCheck1();                      //Set 2-line cursor
   WriteCommand(0xa1);

   ClearScreen();
   PrintLine("Bonjour!",1);
   StatusCheck1();
   WriteCommand(0x94);                 //Text On, Graphic Off
   StatusCheck1();
```

```
  i = 50000;
  do i--;
  while (i!=0);

  GenerateGraphics();
}
```